Electrical Characteristics of Transmission Circuits

ELECTRICAL CHARACTERISTICS OF TRANSMISSION CIRCUITS

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BY

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PREFACE

The rapid expansion in the use of electricity is necessitating a tremendous amount of arithmetical labor in connection with the solution of projected transmission and distribution circuits. This is demanding much valuable time and energy in the education of the younger engineers now going through the technical schools and others who will follow them. It was largely to assist these younger engineers by making their work easier and less liable to error, and providing them with all necessary tools, that the data in this book have been compiled.

Many articles, each pertaining to some particular method of solution of transmission circuits, have from time to time been published. This book constitutes a review of each of numerous methods previously proposed by various authors with examples illustrating each method of solution and the accuracy which may be expected by its use. Thus, the user is provided with a choice of numerous methods ranging between the most simplified graphical forms of solutions and complete mathematical solutions. He is also provided with numerous and extensive tables of circuits and other constants making it unnecessary for him to lose time and risk making mistakes in calculating constants for each case in question. Much effort has been expended with a view to simplifying explanations by the aid of supplementary diagrams and tabulations. The engineer to whose lot it only occasionally falls to determine the size of conductors and performance of circuits appreciates how easy it is to make errors in calculations which may prove very serious. He should find the quick estimating tables for short lines and the tables of 60-cycle auxiliary constants (in the back of the book) for long line solutions a great aid in his work. If the frequency be 25 or 50 cycles, Wilkinson's simplified formulae for long lines will shorten his work. Some of the solutions contained in this book are now of academic interest only. For instance, since tables of 60-cycle auxiliary constants have been calculated and tabulated there would be no object in determining these constants by the graphical methods given in the book.

Some diagrams and problems used in this edition are based upon linear constants previously taken from older tables of constants. The tables of linear constants in this edition are new. The new resistance tables include skin effect and the new reactance tables include stranding effect whereas the older tables did not. The tables on A. C. S. R. cables take into account the effect of the steel strands on resistance and inductance. This explains the slight discrepancy between the values of some of the constants used in the diagrams and problems and those listed in the present new tables of constants.

This edition constitutes a slight revision plus a large addition to the original articles, "Electrical Characteristics of Transmission Circuits" published serially in the *Electric Journal* and later in book form by the Westinghouse Electric and Manufacturing Co. The principal revisions consist of new tables of linear constants which take into account skin effect, stranding effect and the effect of steel strands in A. C. S. R. cables. The principal additions consist of tables of auxiliary constants, a chapter on insulators, one on general circuit constants and circle diagrams, one on stability of circuits and one on tabulated data on existing lines.

The following engineers have contributed in the making up of this edition: Ralph W. Atkinson, Herbert B. Dwight, Robert D. Evans, Charles Fortescue, T. B. Fleming, Fred. C. Hanker, Dr. Arthur E. Kennelly, George E. Luke, Dr. Addams S. McAllister, Ralph D. Mershon, Frank W. Peek, Jr., John F. Peters, Charles R. Riker, Walter S. Rugg, Hollis K. Sels, Paul E. Schweizer, Percy H. Thomas, Theodore Varney, C. F. Wagner, Professor William R. Work and Thomas A. Wilkinson. Mr. Wilkinson laid out the methods used and supervised the work of calculating the linear and auxiliary constants as tabulated in the back of the book. Mr. Schweizer made the calculations for all table values. Messrs. Evans, Fortescue Peters and Fleming contributed much valuable and helpful material. The new and very complete data upon linear constants of aluminum cables, steel reinforced, being fundamental, constitute a most valuable addition to this book; this data is available through the courtesy and cooperation of Mr. Varney of the Aluminum Company of America and is the result of many very complete and accurately made tests by Prof. Work of the Carnegie Institute of Technology of Pittsburgh, Pa.

The series of articles entitled "Mechanical Characteristics of Transmission Circuits" by L. E. Imlay in the Electric Journal will soon be available in book form. This book will be found very helpful to those concerned with the mechanics of transmission lines.

Wm. Nesbit

CONTENTS

ERRATA:

—Reference: Table headings, Pages 164 and 165—

"25 cycle", page 164, should read, "60 cycle".

"60 cycle", page 165, should read, "25 cycle".

ELECTRICAL CHARACTERISTICS OF TRANSMISSION CIRCUITS

CHAPTER I

THE THREE CIRCUITS—RESISTANCE AND SKIN EFFECT

THE THREE CIRCUITS

The transmission of alternating-current power involves three separate circuits, one of which is composed of the wires forming the transmission line, while the others lie in the medium surrounding the wires. The constants of these circuits are interdependent; although any one may vary greatly from the others in magnitude.* There is first the electric circuit through the conductors. Then since all magnetic and dielectric lines of force are closed upon themselves forming complete circuits there is a magnetic and a dielectric circuit. The magnetic circuit consists of magnetic lines of force encircling the current carrying conductors and the dielectric circuit the dielectric lines of force terminating in the current carrying conductors. The close analogy of these is given in Table A, a careful study of which will help those not familiar with the subject to a clearer understanding of what happens in an alternating-current transmission circuit.

For a unidirectional constant current the magnetic field remains constant, and similarly for a unidirectional constant voltage the dielectric field is constant. With both the current and the voltage unidirectional and constant, the electric circuit alone enters into the calculations. A changing magnetic flux introduces a voltage into the electric circuit which modifies the initial or impressed voltage. This effect of the magnetic circuit, which is measured by the inductance L, storing the energy $0.5i^2L$, is a function of the current, and hence is of most importance in dealing with heavy current circuits. Similarly a changing electrostatic flux adds (vectorially) a current to the main power current. This effect of the dielectric circuit, which is measured by the capacitance, storing the energy $0.5e^2C$, is a function of the voltage, and hence is of most importance in dealing with high-voltage circuits.

In an alternating-current circuit, both the voltage and the current are continually varying in magnitude, and moreover, reversing in direction for each successive half cycle. Therefore, with alternating current, energy changes occur continuously and simultaneously in the interlinked magnetic, dielectric and electric circuits.

Figures 1 to 5 inclusive illustrate the magnetic and dielectric field surrounding conductors carrying current. Figures 1 and 3 represent respectively the magnetic and dielectric circuits when the conductors are far apart and Figs. 2 and 4 when they are close together. Figure 5 represents the resultant of the superimposed magnetic and dielectric fields.

The magnetic field surrounding a conductor which is not influenced by any other field is represented by concentric circles. This field is strongest at the surface of the conductors and rapidly decreases with increasing distance from the conductor as indicated by the spacing of the lines of Figs. 1 and 2.

The dielectric stresses surrounding conductors are represented by lines drawn radially from the conductor. The strength of the dielectric field likewise decreases with the distance from the conductor as is indicated by the widening of the space between the lines. The magnetic and the dielectric lines of force always cross each other at right angles, as shown in Fig. 5.

RESISTANCE OF COPPER CONDUCTORS

In Table III is listed the d.-c. resistance per 1,000 ft. of solid copper conductors for all sizes of the American or Brown and Sharpe Wire Gauge at seven different temperatures from 0 to 75°C. (32 to 167°F.), values being given both for annealed copper of 100 per cent conductivity and hard drawn copper of 97.3 per cent conductivity. In Table IV is given the d.-c., 25-cycle and 60-cycle resistance per 1,000 ft. of stranded conductors of annealed and hard drawn copper for the same conductivities and five of the seven temperatures given in Table III. In Table V is given the resistance per mile of stranded copper conductors corresponding to the values per 1,000 ft. in Table IV. The foot-notes with these tables cover all of the pertinent data upon which the d.-c. values are based, the fundamental data being taken from Circular No. 31 of the Bureau of Standards, Third Edition, issued October 1st, 1914.

The 25-cycle and 60-cycle resistances have been calculated from the rigorous formula for straight cylindrical wires given on page 173 of *Scientific Paper* No. 169 of the Bureau of Standards, using Table XXII in the same publication for the interpolation of the skin effect ratio from the factor x. The resistance values are accurate within .02 per cent. As shown below in the section on skin effect the values calculated for solid conductors are closely accurate for stranded conductors.

It has been customary to publish tables of resistance values based upon a temperature of 20°C. and 100 per

* For a further description of these circuits see "Alternating Currents" by Prof. Carl. E. Magnusson, from which Figs. 1 to 5 are reproduced with the permission of the author.

cent conductivity. The operating temperature of conductors carrying current is usually considerably higher than 20°C. and therefore calculations based upon this temperature do not often represent operating conditions. Neither does copper of 100 per cent conductivity represent the usual condition for transmission circuit copper, whose average conductivity is nearer 97.3 per cent. The values in Tables III, IV and V furnish a comparison of resistance of annealed and hard drawn copper in stranded and solid conductors at various temperatures based upon the "International Annealed Copper Standard."

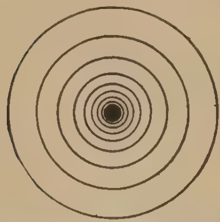

FIG. 1 MAGNETIC FIELD OF SINGLE CONDUCTOR

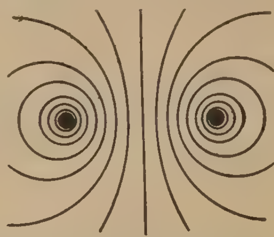

FIG. 2 MAGNETIC FIELD OF CIRCUIT

THE MAGNETIC CIRCUIT

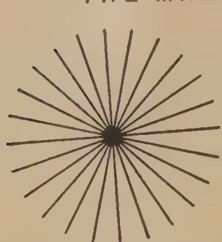

FIG. 3 DIELECTRIC FIELD OF SINGLE CONDUCTOR

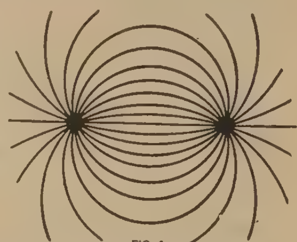

FIG. 4 DIELECTRIC FIELD OF CIRCUIT

THE DIELECTRIC CIRCUIT

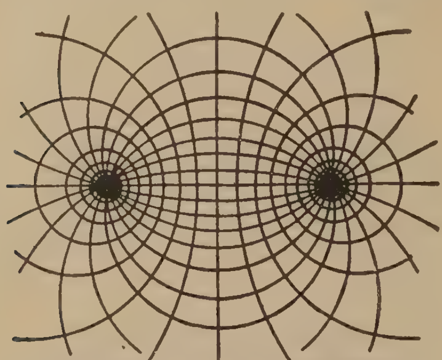

FIG. 5. COMBINED DIELECTRIC AND MAGNETIC CIRCUITS

THE ELECTRIC CIRCUIT

RESISTANCE OF ALUMINUM CONDUCTORS

In Table VI is listed the resistance per mile of aluminum conductors of the type now generally used for overhead transmission circuits and consisting of a steel core about which the aluminum is stranded. This type of conductor is known as Aluminum Cable Steel Reinforced, commonly abbreviated A. C. S. R. Complete details of the physical characteristics of this type of conductor are given in Table II.

In the case of copper or all aluminum conductors the only variables affecting the resistance of a conductor of a particular size and per cent conductivity are the temperature and in the case of alternating current resistance, the frequency. The addition of a steel core having relatively very low conductivity greatly reduces the current flowing in the central portion of the conductor and thus reduces the increase of resistance with alternating current due to "skin effect" as noted and discussed in the section following.

In the place of skin effect in A. C. S. R. conductors are substituted hysteresis and eddy current losses or "iron losses," due to the alternating flux in the steel core. As explained in the section following, the current density becomes an important factor in determining the alternating current resistance of the composite conductor and the a.-c. resistances in Table VI are given at 25°C. for various current densities from 0 to 1,400 amp. per square inch, rather than at various temperatures as in the tables of copper conductors.

The d.-c. resistance values at 0 amp. and 25°C. were calculated from the following fundamental data supplied by the Aluminum Company of America and also given on page 14 of Circular 31 of the Bureau of Standards.

TABLE *A*.—COMPARISON OF THE THREE CIRCUITS

The electric circuit	The magnetic circuit	The dielectric circuit
Current I Voltage $E = RI$ Electric power	Magnetic flux ϕ Magnetomotive force $F = ni$ Magnetic energy	Dielectric flux ψ Electromotive force $E = Q/C$ Dielectric energy
Resistivity Resistance $R = W/I^2$	Reluctivity Reluctance R Inductance $L = \phi/i$	Elastivity $1/K$ Elastance S Capacitance $C = \psi/E$
	Reactance $x = wL - 1/wC$	
Impedance $z = \sqrt{r^2 + x^2}$		
Conductivity γ Conductance $g = W/E^2$ $g = r/z^2$	Permeability $\mu = B/H$ Permeance $M = \phi/4\pi F$	Permittivity K Permittance (Capacitance) C
	Susceptance $b = x/z^2$	
Admittance $y = 1/z = g \pm jb = \sqrt{g^2 + b^2}$		

Conductivity at 20°C........... 61 per cent
Constant mass temperature coefficient of resistance at 20°C..... .0039

The d.-c. resistances calculated from the above data have been increased 2 per cent to allow for the additional length of conductor due to stranding and the conductance of the steel core has been neglected.

The 60-cycle resistance values are based upon accurate tests covering a wide range of sizes and current densities made by Professor William R. Work at the Carnegie Institute of Technology, Pittsburgh, Pa., for the Aluminum Company of America. The tests showed that the number of layers of aluminum over the steel core had a considerable effect on the iron losses and a column showing this factor for each conductor is included in the table.

SKIN EFFECT AND IRON LOSSES

A solid conductor may be considered as made up of separate filaments, just as a piece of wood is made up of separate fibres. As a stranded conductor is actually made up of a number of separate wires, such a conductor will be considered in the following explanation. The inductance of the various wires of the cable will be different, due to the fact that those wires near the center of the cable will be linked by more flux lines than are the wires near the outer surface. The self-induced back e.m.f. will therefore be greater in the wires located near the center of the cable. The higher reactance of the inner wires causes the current to distribute in such a manner that the current density will be less in the interior than at the surface. This crowding of the current to the surface or "skin" of the wire is known as "skin effect."

Since the self-induced e.m.f. is proportional to the frequency as well as to the total flux linked, the skin effect becomes more pronounced at higher frequencies of the impressed e.m.f. It also becomes greater the larger the cross-section, the greater the conductivity and the greater the permeability of the conductor.

As a result the effective resistance of a conductor to alternating current is greater than that to direct current. The problem has been treated mathematically by various authorities and a rigorous solution for the ratio of resistance with alternating current to resistance with direct current for straight cylindrical wires has been published by the Bureau of Standards.[1] It has been shown experimentally[2] that the subdivision of a conductor into parallel untwisted strands in contact with one another produces no perceptible increase of resistance to alternating current as compared with an equisectional solid conductor. The twisting or spiraling of the strands causes an increase of resistance to alternating current as compared with an unspiraled conductor but tests have also shown[2,3] that the increase due to spirality effect is negligible within the limits of frequency and conductor sizes used in overhead transmission circuits. The table values of 25-cycle and 60-cycle resistance of copper conductors, which are calculated on the basis of solid conductors of equal cross-section are therefore closely accurate for stranded conductors.

In the case of Aluminum Cable Steel Reinforced the displacement of the current from the central portion of the conductor is effected to a large extent independently of skin effect by the low conductance of the steel core, which permits only a small proportion of the total current to flow in the central portion of the conductor. Skin effect in the ordinary sense is therefore inappreciable for transmission frequencies and conductor sizes. In its place there is an increase of resistance with alternating current due to hysteresis and eddy currents, or "iron losses" produced by alternating the flux in the steel core. The spiral aluminum strands around the steel core form, in effect, a solenoid with a long pitch winding. The iron losses vary with the flux density in the steel core and therefore with the current flowing in the conductor. The losses therefore vary both with the frequency and the current density. Tests show also that the losses are influenced to a considerable extent by the number of layers of aluminum over the steel core and from the point of view of increase of resistance with alternating current A. C. S. R. conductors fall into three groups, namely; conductors having one, two or three layers of aluminum respectively over the steel core. The losses are greatest, relatively, in single layer conductors, due to the fact that the steel core is subject to the full magnetizing influence of the current in a single layer wound in one direction around it. The losses in a two layer conductor, on the other hand, are negligible, due to the fact that the two layers are wound in opposite directions, thus cancelling the magnetizing effect except for a small resultant effect due to one layer being at a greater distance from the core than the other layer. It will be noted from Table VI that there is no increase of resistance to alternating current in the two-layer group of conductors, except in the case of two of the largest conductors at high current densities. The three-layer group of conductors shows an increase of resistance intermediate between that of the single-layer and two-layer groups, due to the unbalanced action of the third or outer layer, the effect of this layer being smaller than that of the first layer, due to the larger radius of the winding.

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CHAPTER II

INDUCTANCE AND REACTANCE

Any moving mass, for instance a flywheel in motion, will resist a change in velocity. That is, the inertia of the moving mass will tend to keep the mass moving when disconnected from the source of power. On the other hand the inertia will oppose any effort to speed up the movement of the mass.

In a similar manner, the inductance of an electric circuit resists a change in current. The cause of inductance in an electric circuit is the magnetic field which surrounds the circuit. When the current changes this magnetic field changes correspondingly, and in effect cuts the conductor, producing an e.m.f. in it. This e.m.f. of self induction has such a direction as to resist the change in current. While the current is increasing, energy is stored in the magnetic field and while the current decreases, the magnetic stored energy is returned to the electric circuit. This effect of the electric current on the surrounding space is termed magnetic induction.

UNIT OF INDUCTANCE

When a rate of change of current of 1 amp. per second produces an e.m.f. of one volt, the circuit is said to have a unit of inductance called a henry. The henry being inconveniently large, a thousandth part of it, called the milli-henry, is the usual practical unit. This unit is the coefficient of self-induction and is represented by the letter L.

DISTRIBUTION OF FLUX

When current flows through a conductor, a magnetomotive force (m.m.f.) is established of a value proportional to the current. This m.m.f. is of zero value at the center of the conductor and increases as the square of the distance from the center until the surface is reached. (This statement as well as those following is based upon the assumption of a uniform distribution of current throughout the conductor, the conductor being of non-magnetic material and located in non-magnetic surroundings, such as air). At the surface it becomes maximum for a given current and remains at this maximum value for all distances beyond the surface.

It is customary to think of the magnetic field surrounding conductors as concentric circles of lines of force. A physical picture of the magnetic field density surrounding a current carrying conductor A is shown by Chart I. The magnetic density due to the return circuit (Conductor B) is indicated in outline by broken lines. The horizontal divisions represent the distance from the center of conductor A and the height of the curve measured vertically the intensity of the field at the corresponding distance. The radius of the conductor has been assumed as unity, and maximum field density (always at the surface of the conductor) as 100 per cent.

The intensity of the magnetic field starts at zero at the conductor center, and increases (with uniform distribution of current in the conductor) directly as the distance from its center until its surface is reached, where it becomes maximum. For distances beyond the surface of the conductor, the field intensity varies inversely as the distance from its center.

The intensity of the magnetic field at any point is proportional to the m.m.f. acting at that point and inversely proportional to the length of its circular path (magnetic reluctance). Thus at the surface of the conductor the m.m.f. reaches its maximum because all the current in the conductor is acting to produce m.m.f. at this and all points beyond. On the other hand the circular path subject to this maximum m.m.f. is shortest at the surface, the reluctance is a minimum and consequently the field intensity is greatest. For points beyond the surface the length of the circular path through air is proportional to the distance from the center of the conductor. Thus at a distance of 2 from the center the circular path is twice as long as at a distance of 1 (its surface) and consequently, although the m.m.f. is the same the reluctance is double, permitting only one-half as great a flux to flow as at the surface. For a similar reason the density of the field at a distance of 10 is one-tenth the surface density; at 50 it is one-fiftieth, etc. The curve of field density beyond the surface of the conductor therefore assumes the form of a hyperbola.

Inside conductor A the field density is represented by a straight line joining the center of the conductor to the apex of the density curve, represented as 100 per cent. Suppose it is desired to determine the field density at a point midway between the center and surface of the conductor. At this point the length of the circular path is one-half its length at the conductor surface. Since the current is assumed as distributed uniformly throughout the cross-section of the conductor, at a point midway between the center and its surface, one-fourth of the total current would be embraced by the circle. The m.m.f. corresponding to this point would therefore be one-fourth its value at the surface. With one-fourth m.m.f. and one-half the surface reluctance the resulting density will be one-half of the surface density as shown by this value falling on the straight line at this distance from the center.

The m.m.f. resulting from equal currents is the same for all sizes of conductors. Thus the field density

at points equally distant from the center of different sizes of conductors carrying equal currents is equal provided these points lie beyond the surface of the largest conductor. For points equally distant from the center of different size conductors which lie inside the conductors the density will be different. Thus if the conductor diameter carrying equal current be reduced to one-half, the m.m.f. at its surface will remain the same, but since the flux path at the surface is now only one-half as long, the flux density at the surface will be twice as great. In other words, the magnetic field density at the surface of conductors having different diameters but carrying the same currents is inversely proportional to their diameters.

The area indicated by cross-sectional lines on the inductance chart represents the amount of inductance effective in conductor A resulting from current in that conductor. It will be seen that the total area between the adjacent surfaces of the conductors at 1 and 9 below the flux density line is effective. This part of the inductance follows a logarithmic curve as illustrated on the chart and is represented by the formula

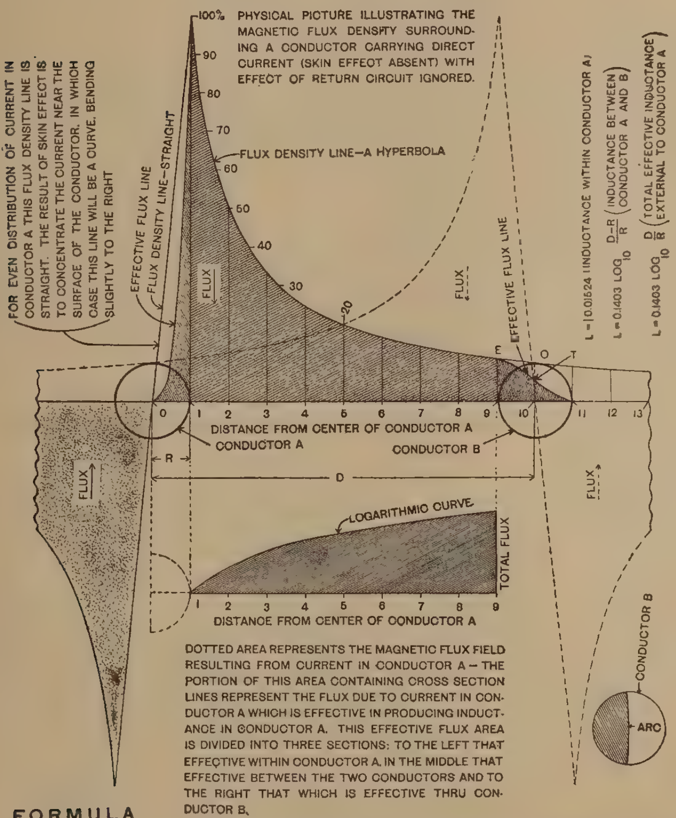
$$L = 0.14037 \log_{10} \frac{D - R}{R} \qquad (1)$$

Where L is in millihenries per 1,000 ft. of single conductor.

The effective flux area departs from the flux density line at E dropping down in the form of a reverse curve and terminating in zero at 11. All flux to the right of 11 cuts the whole of both conductors producing the same amount of inductance in both of them in such a direction as to oppose or neutralize each other.

The flux cutting conductor B from 9 to 11 has its full value of effectiveness in producing inductance in conductor A. On the other hand it also produces to a less extent inductance in conductor B but in a direction to oppose that which it produces in conductor A. The difference between that produced in conductors A and B is the effective flux producing inductance in the circuit and is represented by the shaded portion through conductor B within the area E-9-11-T-E. To illustrate how the effective flux curved line E-T-11 was determined, suppose it is required to determine the effective flux at the distance 10 (center of conductor B). At this point the flux density is 10 per cent, but since these flux density lines are actually concentric circles, having their center at the middle of conductor A this flux density curve cuts conductor B in the form of an arc (see lower

CHART I—INDUCTANCE



FORMULA

TOTAL INDUCTANCE IN MILLIHENRIES (L) PER 1000 FEET OF EACH CONDUCTOR $L = 0.01524 + 0.1403 \log_{10} \frac{D}{R}$

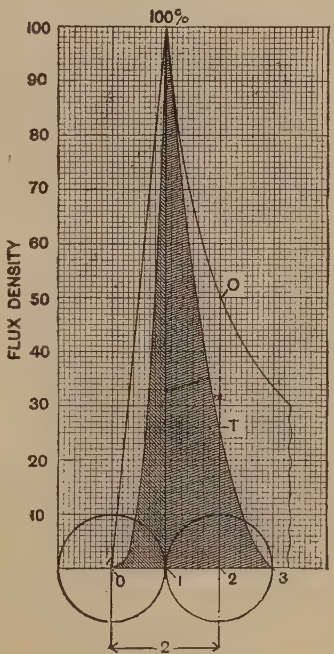


FIG. 6.

right hand corner of inductance chart). The area of the shaded portion between the two arcs is a measure of the inductance in conductor B at its center. The difference between this shaded area, and the whole area of B, or the clear part to the right of the shaded portion, is a measure of the difference in inductance of the two conductors. In other words, for the spacing shown, approximately 55 per cent of 10 or 5.5 per cent is the value of the effective flux at distance of 10 from conductor A.

If in place of $L = 0.14037 \log_{10} \dfrac{D-R}{R}$ (1)

we take

$$L = 0.14037 \log_{10} \frac{D}{R} \qquad (2)$$

we include all of the inductance area out to the vertical line 0-10. This would include the area E-0-T but not the area T-10-11. Since these two areas are equal, the omission of one is balanced by including the other and therefore formula (2) correctly takes into account all of the effective inductance beyond the surface of conductor A.

The inductance within conductor A is determined as follows: At a point midway between the center and its surface the flux density is 50 per cent as indicated by the straight flux density line of the chart. However at this point only one-fourth of the conductor area is enclosed, so that, measured in terms of its effect if outside the conductor, its effectiveness would be only one-fourth of 50 or 12.5 per cent. This is the reason that the so-called effective flux line is curved and falls to the right of the straight flux density line. The area of the shaded section 0-1-100 is a measure of the effective inductance within conductor A. This is a constant for all sizes of conductors and is represented by the constant 0.01524 of the inductance formula based upon 1,000 ft. of conductor.

The fundamental formula for the total effective inductance (within and external to conductor A) of a single solid non-magnetic conductor suspended in air is therefore:

$$L = 0.01524 + 0.14037 \log_{10} \frac{D}{R} \text{ per 1,000 ft.} \qquad (3)$$

or

$$L = 0.08047 + 0.74113 \log_{10} \frac{D}{R} \text{ per mile} \qquad (4)$$

It may be interesting to note here that the above described graphical solution for inductance produces results in close agreement with those obtained by the fundamental formula for inductance. That is, lay out such a chart on cross-section paper to a large scale and count the number of squares or area representing the internal and the external inductance due to current in conductor A. It will be seen that the relative values of the external and internal flux areas conform with the relative values as determined by the formula. This will also be true in the case of the conductors when so placed as to give zero separation, as illustrated by Fig. 6.

The minimum value of inductance occurs when the conductors have zero separation or $D/R = 2$ (Fig. 6). In this case the inductance in millihenries is independent of the size of the conductor. As given by formula (3) it is $L = 0.01524 + 0.1403 \log_{10} 2 = 0.575$ millihenries per 1,000 ft. of each conductor. Obviously insulation requirements will not admit of such a low value for inductance although it will be closely approached in low-voltage cables.

Any given percentage difference in distance between centers of conductors represents a definite and constant change in value of inductance or reactance regardless of their size. These values are given at the bottom of Tables VII to XII for various percentage increases in spacings or values of D'/D. Thus if the distance between conductor centers is increased 50 per cent the corresponding increase in inductance, or $L+$, is 0.1305 as indicated under the D'/D value of 1.50 on Tables VII and VIII. The increase in 25-cycle reactance, or $X+$, for the same percentage increase of spacing is 0.020, as shown on Tables IX and X. Likewise doubling the distance increases the inductance by the amount 0.2231 and the 25-cycle reactance by the amount 0.035. For instance the table value of inductance of No. 0 copper conductor at 2-in. spacing is to three decimal places 0.871 and at 4-in. spacing is 1.094, an increase of 0.223. The corresponding values of 25-cycle reactance are 0.137 and 0.172, an increase of 0.035.

VARIATIONS FROM THE FUNDAMENTAL INDUCTANCE FORMULA

It has been proven mathematically by the Bureau of Standards and others that the fundamental formula (3) for determining inductance will give exact results for solid, round straight, parallel conductors, provided skin and proximity effects are absent. Proximity effect is the crowding of the current to one side of a conductor, due to the proximity of another current carrying conductor. It is similar to skin effect in that it increases the resistance and decreases the inductance. Proximity effect as well as skin effect changes only the inductance due to the flux inside the conductor. Proximity effect is more pronounced for large conductors, high frequencies and close proximity.

For No. 0000 solid conductors at zero separation and 60 cycles, the error in the results (as determined by the fundamental inductance formula) due to skin effect is less than one-tenth of 1 per cent. This error, however, increases, rapidly as the size of the conductor increases. Proximity effect cannot be calculated but it is believed to be less than 2 per cent in the above case.

Should skin and proximity effect combined be sufficient to force all of the current out to within a very thin annulus at the surface of the conductor (a condition obviously never obtained at commercial frequencies) their combined effect would be a maximum. In such a case there would be no inductance within the conductors and the first constant 0.01524 would disappear from formula (3).

Skin and proximity effect are so small in the case of the greater spacings of conductors required for high tension aerial transmission ciruits that they may in such cases be ignored. Even in the case of the close spacings required for three-conductor cables these combined effects are usually less than 4 per cent.

Effect of Stranding upon Inductance

The fundamental formula (3) for determining inductance is based upon a solid conductor, R being taken as the radius of the conductor. In stranded cables the effective value for R lies between the actual radius and that of a solid rod having an equivalent cross-section to that of the cable. The effective value of R varies with the stranding of the cable employed.

Formulas for use in determining the inductance of stranded conductors have been developed by Mr. H. B. Dwight.* These formulas, extended to cover all of the cases of copper stranding occurring in the tables herein are as follows:

For a 7-strand conductor, $L = 0.74113 \log_{10} \dfrac{2.756D}{d}$

For a 19-strand conductor, $L = 0.74113 \log_{10} \dfrac{2.640D}{d}$

For a 37-strand conductor, $L = 0.74113 \log_{10} \dfrac{2.605D}{d}$

For a 61-strand conductor, $L = 0.74113 \log_{10} \dfrac{2.590D}{d}$

For a 91-strand conductor, $L = 0.74113 \log_{10} \dfrac{2.583D}{d}$

For a 127-strand conductor, $L = 0.74413 \log_{10} \dfrac{2.579D}{d}$

where L is in millihenries per mile of single conductor, D is the distance between centers of conductors and d is the outside diameter of the conductors, expressed in the same units as D.

For convenience in calculating the inductance directly from the circular mils without the necessity of first determining the diameter of the conductor, the above formulas are given in a footnote to Table VII in terms of the distance D and the circular mils.

Effect of Spiraling upon Inductance

Spiraling of the strands of a cable and spiraling of the conductors of a three-conductor cable tend to increase the inductance. It is difficult to calculate the effect of spiraling for the various cases, but it may be considered negligible for high-tension aerial transmission circuits using non-magnetic conductors. For three-conductor cables the effect of spiraling is probably in the neighborhood of 2 per cent.

Effect of Steel Core upon Inductance

Tests upon the inductance of Aluminum Cable Steel Reinforced show several peculiarities of this type of cable as compared with non-magnetic conductors. It is found that the inductance of conductors having more than one layer of aluminum over the steel core is less than that of copper or all aluminum conductors having the same stranding and over-all diameter. Also the inductance of this group of conductors is practically

INDUCTANCE PER MILE OF SINGLE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

(FOR LARGER SPACINGS SEE TABLE VIII IN BACK OF BOOK).

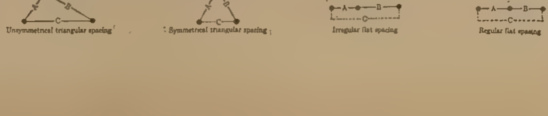
MULTIPLE LAYER CONDUCTORS—ALL CURRENT DENSITIES

CIRCULAR MILS OR A W G. (B & S) (ALUMINUM)	NUMBER OF WIRES		COPPER EQUIVALENT CIRCULAR MILS OR A W G BASED UPON COPPER 97% ALUMIN. 61%	INDUCTANCE L IN MILLIHENRIES PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO- PHASE OR THREE-PHASE CIRCUIT. DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★								
	ALUM	STEEL		2 INCHES 5.1 CM.	4 INCHES 10.2 CM.	6 INCHES 15.2 CM.	8 INCHES 20.3 CM.	10 INCHES 25.4 CM.	12 INCHES 30.5 CM.	15 INCHES 38.1 CM.	18 INCHES 45.7 CM.	21 INCHES 53.3 CM.
1590000	54	7	1000000	.329	.552	.682	.775	.847	.906	.977	1.04	1.09
1510500	54	7	950000	.336	.558	.689	.782	.853	.912	.984	1.04	1.09
1431000	54	7	900000	.344	.566	.697	.790	.861	.920	.992	1.05	1.10
1351500	54	7	850000	.352	.574	.705	.798	.869	.928	1.00	1.06	1.11
1272000	54	7	800000	.362	.584	.715	.807	.879	.938	1.01	1.07	1.12
1192500	54	7	750000	.372	.594	.725	.817	.889	.948	1.02	1.08	1.13
1113000	54	7	700000	.381	.604	.734	.827	.899	.957	1.03	1.09	1.14
1033500	54	7	650000	.392	.615	.745	.838	.910	.968	1.04	1.10	1.15
954000	54	7	600000	.405	.628	.758	.851	.923	.981	1.05	1.11	1.16
900000	54	7	566000	.414	.636	.767	.859	.931	.990	1.06	1.12	1.17
874500	54	7	550000	.418	.640	.771	.863	.935	.994	1.07	1.12	1.17
795000	54	7	500000	.433	.655	.786	.879	.950	1.01	1.08	1.14	1.19
715500	54	7	450000	.450	.672	.803	.896	.967	1.03	1.10	1.16	1.21
666600	54	7	419000	.462	.684	.815	.908	.979	1.04	1.11	1.17	1.22
636000	54	7	400000	.469	.691	.822	.915	.986	1.05	1.12	1.18	1.23
605000	54	7	380500	.477	.699	.830	.923	.994	1.05	1.13	1.18	1.23
556500	30	7	350000	.477	.699	.830	.923	.994	1.05	1.13	1.18	1.23
556500	26	7	350000	.492	.714	.845	.938	1.01	1.07	1.14	1.20	1.25
518000	42	19	326000	.462	.684	.815	.908	.979	1.04	1.11	1.17	1.22
500000	30	7	314500	.494	.716	.847	.940	1.01	1.07	1.14	1.20	1.25
477000	30	7	300000	.502	.724	.855	.948	1.02	1.08	1.15	1.21	1.26
477000	26	7	300000	.517	.739	.870	.963	1.03	1.09	1.17	1.22	1.27
397500	30	7	250000	.534	.756	.887	.980	1.05	1.11	1.18	1.24	1.29
397500	26	7	250000	.549	.771	.902	.995	1.07	1.13	1.20	1.26	1.31
336400	30	7	0000	.562	.784	.915	1.01	1.08	1.14	1.21	1.27	1.32
336400	26	7	0000	.577	.799	.930	1.02	1.09	1.15	1.23	1.28	1.33
300000	30	7	188800	.582	.804	.935	1.03	1.10	1.16	1.23	1.29	1.34
300000	26	7	188800	.598	.820	.951	1.04	1.12	1.17	1.25	1.31	1.35
266800	26	7	000	.613	.835	.966	1.06	1.13	1.19	1.26	1.32	1.37
SINGLE LAYER CONDUCTORS CURRENT DENSITY 0 AMPERES PER SQUARE INCH												
266800	6	7	000	.661	.883	1.01	1.11	1.18	1.24	1.31	1.37	1.42
0000	6	1	00	.813	1.04	1.17	1.26	1.33	1.39	1.46	1.52	1.57
000	6	1	0	.856	1.08	1.21	1.30	1.37	1.43	1.50	1.56	1.61
00	6	1	1	.894	1.12	1.25	1.34	1.41	1.47	1.54	1.60	1.65
0	6	1	2	.930	1.15	1.28	1.38	1.45	1.51	1.58	1.64	1.69
1	6	1	3	.963	1.19	1.32	1.41	1.48	1.54	1.61	1.67	1.72
2	6	1	4	.995	1.22	1.35	1.44	1.51	1.57	1.64	1.70	1.75
3	6	1	5	1.03	1.25	1.38	1.47	1.54	1.60	1.68	1.73	1.78
4	6	1	6	1.06	1.28	1.41	1.51	1.58	1.64	1.71	1.77	1.82
5	6	1	7	1.09	1.32	1.45	1.54	1.61	1.67	1.74	1.80	1.85
6	6	1	8	1.13	1.35	1.48	1.58	1.65	1.71	1.78	1.84	1.89
SINGLE LAYER CONDUCTORS CURRENT DENSITY 600 AMPERES PER SQUARE INCH												
266800	6	7	000	.708	.930	1.06	1.15	1.23	1.28	1.36	1.42	1.46
0000	6	1	00	.866	1.09	1.22	1.31	1.38	1.44	1.51	1.57	1.62
000	6	1	0	.893	1.12	1.25	1.34	1.41	1.47	1.54	1.60	1.65
00	6	1	1	.921	1.14	1.27	1.37	1.44	1.50	1.57	1.63	1.68
0	6	1	2	.949	1.17	1.30	1.40	1.47	1.53	1.60	1.66	1.71
1	6	1	3	.979	1.20	1.33	1.43	1.50	1.56	1.63	1.69	1.74
2	6	1	4	1.01	1.23	1.36	1.45	1.52	1.58	1.66	1.71	1.76
3	6	1	5	1.04	1.26	1.39	1.48	1.55	1.61	1.68	1.74	1.79
4	6	1	6	1.06	1.29	1.42	1.51	1.58	1.64	1.71	1.77	1.82
5	6	1	7	1.10	1.32	1.45	1.55	1.62	1.68	1.75	1.81	1.86
6	6	1	8	1.14	1.36	1.49	1.58	1.65	1.71	1.79	1.84	1.89
SINGLE LAYER CONDUCTORS CURRENT DENSITY 1200 AMPERES PER SQUARE INCH												
266800	6	7	000	.919	1.14	1.27	1.37	1.44	1.50	1.57	1.63	1.68
0000	6	1	00	.939	1.16	1.29	1.39	1.46	1.52	1.59	1.65	1.70
000	6	1	0	.973	1.20	1.33	1.42	1.49	1.55	1.62	1.68	1.73
00	6	1	1	.998	1.22	1.35	1.44	1.52	1.57	1.65	1.71	1.75
0	6	1	2	1.02	1.24	1.37	1.46	1.53	1.59	1.66	1.72	1.77
1	6	1	3	1.03	1.25	1.39	1.48	1.55	1.61	1.68	1.74	1.79
2	6	1	4	1.04	1.27	1.40	1.49	1.56	1.62	1.69	1.75	1.80
3	6	1	5	1.06	1.28	1.41	1.50	1.57	1.63	1.71	1.76	1.81
4	6	1	6	1.07	1.30	1.43	1.52	1.59	1.65	1.72	1.78	1.83
5	6	1	7	1.12	1.34	1.47	1.56	1.63	1.69	1.76	1.82	1.87
6	6	1	8	1.15	1.37	1.50	1.60	1.67	1.73	1.80	1.86	1.91

By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The inductance values of the table are based upon actual tests on various sizes of cable at various current densities at one foot spacing. The inductances at other spacings were calculated from those at one foot spacing by means of the fundamental inductance formula.

★ For any three-phase arrangement of conductors $D \cong \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



* H. B. Dwight: "Transmission Line Formulas," and "Constant Voltage Transmission."

constant and independent of the current flowing in the conductor. On the other hand, the inductance of conductors having only one layer of aluminum over the steel core is found to be greater than that of the corresponding homogeneous non-magnetic conductor of the same stranding and outside diameter. Also the inductance of these single-layer conductors is found to vary with the current, increasing with the higher-current densities.

The smaller inductance of multiple-layer conductors is due to the fact that the current in the central portion of the conductor is small, on account of the low conductance of the steel core, thus reducing the linkage and approximating the current distribution in a tube. The reversal of the direction of spiraling in successive layers of aluminum wholly or partially cancels the solenoid effect, the net result being a smaller inductance practically independent of current density.

In the case of single-layer conductors, while the current in the steel core is small, thus tending to reduce the inductance, the solenoid effect of the single layer of aluminum is apparently greater than the reducing effect of the steel core, the result being an increase of inductance, which increase is variable, depending on the current flowing in the conductor.

Tables of Inductance

Values of inductance for all sizes of copper conductors from 2,000,000 circular mils to No. 6 A.W.G. and for spacings from 2 in. to 35 ft. are given in Table VII. These values, as explained in a footnote to the table, are based on the exact formulas of Mr. H. B. Dwight for stranded conductors.

The inductance of Aluminum Cable Steel Reinforced is given in Table VIII. This table includes all regular sizes and strandings made at this time by the Aluminum Company of America, from, 1,590,000 circular mils to No. 6 A.W.G. and spacings from 2 ft. to 35 ft. A supplementary table for smaller spacings is given in an adjacent column.

The inductance values of Table VIII are based upon laboratory tests made by Professor William R. Work at the Carnegie Institute of Technology, Pittsburgh, Pa., for the Aluminum Company of America. The tests were made at 1 ft. spacing and for other spacings the values have been calculated from those at 1 ft. spacing by means of the fundamental inductance formula.

REACTANCE

A conductor carrying an electric current is surrounded by a magnetic flux, whose value is proportional to the current. If the current varies, this flux also changes, thereby inducing an electromotive force in a direction which opposes the change. This counter e.m.f. is proportional to the rate of change and hence in alternating current is proportional to the frequency. It can be expressed in ohms per mile of each conductor of a single-phase, two-phase or three-phase circuit as follows:

Ohms Reactance $= 2\pi fL$ (9)

When $f =$ frequency in cycles per second

$L =$ henries per mile of single conductor

The value for $2\pi f$ are as follows:

Frequency	$2\pi f$
1	6.28
15	94.25
25	157.1
40	251.3
50	314.2
60	377.0

Tables IX and XI indicate the 25- and 60-cycle reactance, respectively, in ohms per mile of single conductor, of copper conductors at various spacings. The corresponding reactance at 25- and 60-cycles, respectively, of Aluminum Cable Steel Reinforced, is given in Tables X and XII. The footnotes to these tables cover the pertinent points relating to them.

In Tables XIII and XV are shown the ratio of 25-cycle reactance to 25-cycle resistance and the ratio of 60-cycle reactance to 60-cycle resistance, respectively for copper conductors and in Tables XIV and XVI are shown the corresponding ratios for Aluminum Cable Steel Reinforced. These four tables are based on the resistance at 25°C. and indicate the relative importance of reactance and resistance. In some cases of short lines with large conductors the reactance and not the resistance may determine the size and number of cables necessary. In other words, it may be necessary to keep the resistance abnormally low so that the reactance will not be so high as to result in an abnormal voltage drop in the circuit. In such cases the values in Tables XIII to XVI are useful in determining a suitable conductor in order not to exceed the desired reactance.

Example.—It is desired to use a circuit of 1,000,000 c.m. copper conductors at 60 cycles, spaced 2 ft. apart; from Table XV it is seen that the reactance drop under these conditions is 7.61 times the ohmic drop at 25°C. If an ohmic drop of 5 per cent at 25°C. is suggested the corresponding reactive drop would be 5×7.61 or 38.05 per cent, which would be excessive. If it is desired to limit the reactive drop to 10 per cent in this case, the ohmic drop at 25°C. must not exceed $10 \div 7.61$ or 1.32 per cent.

Unsymmetrical Spacing

The inductance and reactance (also capacitance) per conductor of a three-phase circuit for symmetrical spacing of conductors is the same as the inductance and capacitance per conductor of a single-phase circuit for the same size conductor and the same spacing. For irregular spacing of conductors, the inductance, reactance and capacitance will be different. When the three conductors are placed in same plane (flat spacing), the inductance of each of the outside conductors is greater than that of the middle conductor. By properly transposing the conductors, the inductance and capacitance may be equalized in all three conductors. However, the effect of flat spacing is equivalent to that of a symmetrical arrangement of greater spacing.

Various arrangements of conductors are indicated in Figs. 7, 8, and 9. Many three-phase high tension circuits have the three conductors regularly spaced in a common plane (regular flat spacing) Fig.9. Beneath these figures are placed statements indicating the

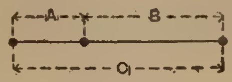


FIG. 7.

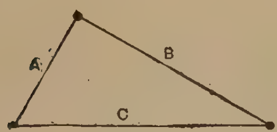


FIG. 8.

FIG. 9.—Conductor spacings.

For three-phase irregular flat or triangular spacing (Figs. 7 and 8) use $D = \sqrt[3]{ABC}$.

For three-phase regular flat spacing Fig. 9 use $D = 1.26A$.

For two-phase line the spacing is the average distance between centers of conductors of the same phase. It makes no difference whether the plane of the conductors with flat spacing is horizontal, vertical or inclined.

determination of "effective spacings" for any arrangement of conductors.

Since the so-called "effective spacing" corresponding to unsymmetrical arrangements of conductors is usually a fractional number, the line constants for such effective spacing can usually not be taken directly from the tables but the inductance and reactance may be obtained by the use of the interpolation values in footnotes to Table VII to XII.

Example.—It is desired to determine the 60-cycle reactance per mile of a single conductor for flat spacing of 11 ft. between adjacent 0000 copper conductors. The effective spacing is 1.26×11 or 13.8 ft. The reactance (Table XI) for this conductor at 13-ft. symmetrical spacing is 0.815 ohm. The value for D'/D, (bottom of Table XI) $= 13.8 \div 13 = 1.06$. The value of $X+$ corresponding to the value for D'/D of 1.06 is approximately 0.006 which, added to 0.815 gives a reactance of 0.821 ohm for the effective spacing of 13.8 ft. The values of reactance for all effective spacings not included in the Table may be determined in a similar manner.

With an unsymmetrical arrangement of conductors there must be a sufficient number of transpositions of conductors to obtain balanced electrical conditions along the circuit.

CHAPTER III

CAPACITANCE, SUSCEPTANCE AND CHARGING CURRENT

CAPACITANCE

When mechanical force is exerted against a liquid or a solid mass, a displacement takes place proportional to the force exerted and inversely proportional to the resistance offered by the liquid or solid mass subjected to the force. If the mass consists of some elastic material, such as rubber, the displacement will be greater than if it consists of a more solid material, such as metal.

In a similar manner when an e.m.f. is applied to a condenser, a certain quantity of electricity will flow into it until it is charged to the same pressure as that of the applied circuit. A condenser consists of plates of conducting material separated by insulating material known as the dielectric. All electric circuits consist of conductors separated by a dielectric (usually air) and therefore act to a greater or less extent as condensers. The ability of a condenser or any electric circuit to receive the charge is a measure of its "capacity" more properly known as its "capacitance." Just as the rubber mass referred to above will, for a given force, permit of greater displacement so will circuits of greater capacitance permit more current to flow into them for a given e.m.f. impressed.

The process of charging a dielectric consists of setting up an electric strain in it similar to the mechanical strain in a liquid or mass referred to above. If an alternating voltage is impressed upon the terminals of a circuit containing capacitance, the charging current will vary directly with the impressed e.m.f. There is current to the condenser during rising and from the condenser during decreasing e.m.f. Thus the condenser is charged and then discharged in the opposite direction during the next alternation, making two complete charges and discharges for each cycle of impressed e.m.f. (Fig. 10). As long as the e.m.f. at the terminals is changing, the condenser will continue to receive or give out current. The current flowing to and from the condenser, assuming negligible resistance, leads the impressed e.m.f. by 90 electrical degrees.

Definition

The capacitance of a circuit or condenser is said to be one farad when a rate of change in pressure of one volt per second at the terminals produces a current of one ampere. Stated another way, its capacitance in farads is numerically equal to the quantity of electricity in coulombs which it will hold under a pressure of one volt. The farad being an inconveniently large unit, one-millionth part of it, the microfarad, is the usual practical unit.

Capacitance Formula

An exact formula for the capacitance between parallel conductors must take into account the nonuniformity of the distribution of charge around the conductors. Such a formula* is formed by considering the charges as concentrated at the inverse points of the conductors; thus,

$$C = \frac{0.008467}{\cosh^{-1}\dfrac{D}{d}} \tag{10}$$

Where C equals the microfarads per 1,000 ft. of conductor between two parallel bare conductors in air, D, the distance between centers of the conductors and d, the diameter and R the radius of the conductors measured in the same units as D.

Since

$$\operatorname{Cosh}^{-1}X = \log_\epsilon (X + \sqrt{X^2 - 1}) \tag{11}$$

$$C = \frac{0.008467}{\log_\epsilon\left(\dfrac{D}{d} + \sqrt{\left(\dfrac{D}{d}\right)^2 - 1}\right)} \tag{12}$$

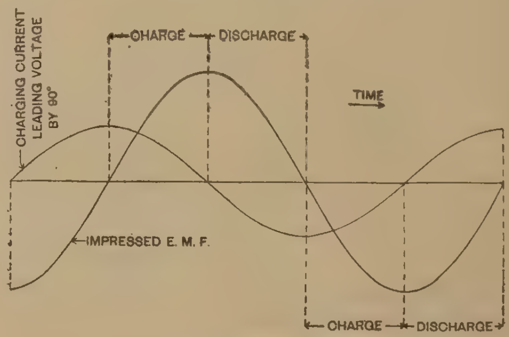


Fig. 10.—Charging current.

Reducing to common logarithms and capacitance to neutral,

$$C = \frac{0.007354}{\log_{10}\left(\dfrac{D}{d} + \sqrt{\left(\dfrac{D}{d}\right)^2 - 1}\right)} \tag{13}$$

Microfarads per 1,000 ft. of single conductor to neutral, or

$$C = \frac{0.038829}{\log_{10}\left(\dfrac{D}{d} + \sqrt{\left(\dfrac{D}{d}\right)^2 - 1}\right)} \tag{14}$$

Microfarads per mile of single conductor to neutral.

When D is greater than $10d$, which is always the case in high-tension transmission lines employing bare

* Pender and Osborne, *Electrical World*, Sept. 22, 1910, Vol. 56.

conductors, the following simplified formulas may be used with negligible error,

$$C = \frac{0.007354}{\log_{10} \dfrac{D}{R}} \qquad (15)$$

Microfarads per 1,000 ft. of single conductor to neutral, or

$$C = \frac{0.03883}{\log_{10} \dfrac{D}{R}} \qquad (16)$$

Microfarads per mile of single conductor to neutral.

The above formulas are only applicable to ordinary overhead circuits when the distance from the conductor to other conductors, particularly the earth, is large compared to their distance apart. However, since the effect of the earth is usually small in most practical cases, the formulas give a very close approximation to the actual capacitance of overhead circuits.

The capacitance to neutral per mile of single bare conductor is given for copper conductors in Table XVII and for Aluminum Cable Steel Reinforced in Table XVIII. The table values were derived by using formula (14) except, as explained in footnotes to the tables, for those conductor sizes and spacings for which the exact and approximate formulas give identical results. In the calculation of the tables the overall diameter of the conductors has been used. This introduces a small error which is negligible except for the closer spacings not used in high tension transmission lines employing bare conductors.

SUSCEPTANCE

It has been explained in the previous chapter that when an alternating current is carried in a conductor an alternating counter e.m.f. is set up in the conductor which is proportional to the rate of change of the current and hence proportional to the frequency. Conversely, when an alternating e.m.f. is applied to a conductor an alternating current flows into and out of the conductor, which, acting as a condenser, is alternately charged and discharged. This charging current is proportional to the rate of change of the voltage and hence proportional to the frequency and to the capacitance of the conductor. It is a measure of the "susceptance" of the conductor. The unit of susceptance is the mho, and its value in mhos per mile is as follows:

Mhos susceptance $= 2\pi fC$.
Where f = frequency in cycles per second.
C = farads per mile of single conductor.

A more convenient unit is the micromho, or one-millionth of a mho, based on the microfarad as the unit of capacity and in terms of this unit,

Micromhos susceptance $= 2\pi fC$.
Where f = frequency in cycles per second.
C = microfarads per mile of single conductor.

Values of $2\pi f$ for various frequencies are given at the beginning of the previous chapter.

Tables XIX and XXI give the 25- and 60-cycle susceptance, respectively, in micromhos per mile of single conductor, of copper conductors at various spacings. The corresponding values for Aluminum Cable Steel Reinforced are given in Tables XX and XXII. The basis of the tables is shown in the footnotes thereto.

CHARGING CURRENT

Relation of Charging Currents of Single- and Three-phase Systems

The diagrams (Fig. 11) may assist in forming a clear understanding of the relation of charging current to susceptance for single- and three-phase circuits. In the following consideration No. 0000 stranded copper conductors will be assumed at a spacing of 9 ft., frequency 60 cycles, voltage 100,000 volts between conductors. Voltage to neutral will therefore be, for a single-phase circuit, 50,000 volts and for a three-phase circuit, 57,740 volts. Distance of transmission 1 mile. From Table XVII a capacitance to neutral of 0.01484 microfarads per mile is obtained. The susceptance will therefore be as follows, where C_n is the capacitance to neutral and C_{12} is the capacitance between conductors 1 and 2.

Per conductor to neutral $2\pi fC_n = 5.59$ micromhos
Between conductors $2\pi fC_{12} = 2.795$ micromhos.

The susceptance to neutral can, of course, be taken directly from Table XXI.

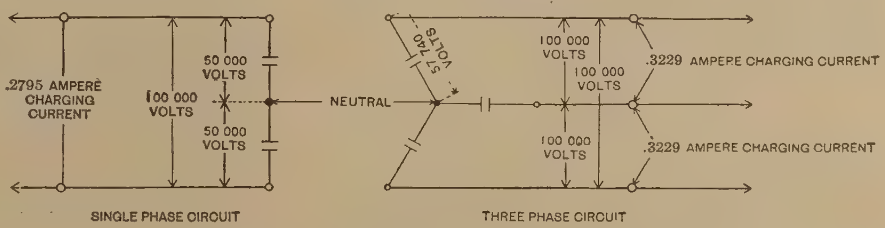


Fig. 11.—Charging current in single and three-phase circuits.

For a Single-phase Circuit.—To neutral charging current equals $5.59 \times 50{,}000 \times 10^{-6} = 0.2795$ amp., therefore charging kv.a. is $0.2795 \times 50{,}000 \times 2 = 27.95$ kv.a. single phase or $0.2795 \times 100{,}000 = 27.95$ kv.a. single phase.

For a Three-phase Circuit.—To neutral charging current equals $5.59 \times 57740 \times 10^{-6} = 0.3228$ amp., therefore charging kv.a. equals $0.3228 \times 57{,}740 \times 3 = 55.9$ kv.a. three-phase.

It will be seen from the above that the charging current per conductor in the three-phase symmetrical system is 15.5 per cent greater than in the single-phase system and the resulting charging kv.a. is just double that of the single-phase system. The charge on any particular conductor is in phase with the voltage

between that conductor and the neutral and the charging current for that conductor is 90 degrees ahead of the voltage drop from that conductor to neutral.

Grounding of the neutral point of a system has no effect upon the charging current when the system is in static balance. In determining the total charging current to be supplied by a given generating station, it should be remembered that in cases of duplicate transmission circuits, when both circuits are excited, the charging current will be approximately double what it would be if only one of the circuits were in use. The effect of branch or any other circuits receiving their excitation from the main line should not be overlooked. The exciting current for transformers connected to the system will tend to neutralize some of the charging current.

The 25- and 60-cycle charging kv.a. in three-phase circuits per mile of three bare copper conductors is given in Table XXIII and the corresponding values for Aluminum Cable Steel Reinforced will be found in Table XXIV.

As indicated, the charging current in amperes per mile of single conductor to neutral = (susceptance from table) $\times$ (volts to neutral) $\times 10^{-6}$. Thus, assuming a three-phase, 60-cycle, 66,000 volt, (38,110 volts to neutral), circuit of 500,000 circ. mils copper conductors spaced 6 ft. apart, the charging current and charging kv.a. per mile would be determined as follows:

Susceptance to neutral (Table XXI) = 6.51 micromhos.

Charging current = $6.51 \times 38{,}110 \times 10^{-6} = .248$ amps. to neutral.

Charging kv.a. = $.248 \times 38.11 \times 3 = 28.4$ kv.a. total three phase.

This value of 28.4 kv.a. is given directly, for the conditions specified, in Table XXIII.

Charging Current at Zero Load

The term charging current of a transmission circuit refers to the amount of current which flows into the circuit at the supply end with normal voltage held at the receiver end at *zero load*. If the circuit is long, its capacitance will be high and therefore the voltage at the supply end may be considerably less than at the receiver end. For instance a 60-cycle circuit 300 miles long, having certain constants will, with 100,000 volts maintained at the receiver end, have a voltage of only 80,000 volts at the supply end at zero load. This same circuit will at full load and 100,000 volts maintained at the receiver end, require 120,000 volts at the supply end. It is evident therefore that, since the charging current varies with the voltage, if the circuit has much capacitance the voltage along the circuit, and particularly near the supply end, will vary to a large extent and consequently the charging current of the circuit will be different for different loads.

In case of the 300-mile circuit referred to above, the charging current at zero load will be very much less than it is at full load, because the average voltage at zero load is less than the average voltage at full load. At zero load the average voltage is less and at full load it is usually greater than the receiver end voltage.

It is customary to calculate the total charging current for the circuit by multiplying the total susceptance by the receiver end voltage. This would be correct if the voltage throughout the length of the circuit were held constant and of the same value as at the receiver end. This condition is approximately met within commercial lines of reasonable length and this method of determining the total charging current is therefore sufficiently accurate for practical purposes.

For the purpose of making exact calculation of the total current at the supply end of long circuits, the charging current must be calculated by mathematical formulas which accurately take into account the change in voltage along the circuit at zero load. This will be taken up in a later article.

Relation of Inductance to Capacitance

As conductors are brought closer together, the inductance decreases and the capacitance increases. These values change with changes in spacings between conductors in such a manner that their product $L \times C$ is practically a constant for all spacings (except very close spacings such as used in low-voltage service and lead-covered cables) and for all sizes of conductors. If there were no losses encountered by the electric propagation in the conductors themselves the product of L and C would be a constant for all spacings and sizes of conductors.

In Table C is indicated the relation of the total inductance and capacitance, and their product, in two bare parallel conductors in air for a circuit one mile long. The values for L are in millihenries and for C in microfarads. Since the formulas by which L and C were calculated account for the flux within the conductors themselves, the product LC is not a constant, as will be seen by the tabulated values, although for the larger spacings such as used in high-tension transmission the product is nearly a constant.

Table C.—Product of (Total) L and (Total) C

Solid conductors		Spacing inches	Inductance L formula (4)	Capacitance C formula (14)	Product LC
Size	Diam. inches				
1,000,000	1.00	2	1.053	0.03395	0.03575
1,000,000	1.00	24	2.653	0.01155	0.03064
1,000,000	1.00	300	4.279	0.00695	0.02974
0000	0.46	2	1.553	0.02079	0.03228
0000	0.46	24	3.153	0.00961	0.03030
0000	0.46	300	4.779	0.00623	0.02977

Relation of Inductance and Capacitance to Light Velocity

The propagation of the electric and the magnetic fields in a dielectric, such as air, is the same as that of light. Along a transmission line it is retarded only

slightly due to losses or the fact that the current is not confined to the surface of the conductors. If the inductance inside the conductors is negligible, then the velocity of the electric and the magnetic fields is the same as light, that is approximately 186,000 miles per second or approximately 3×10^{10} cm. per second. For high-tension transmission lines of large spacings, the inductance inside the conductor is relatively small, so that the speed of the electric field is practically that of light.

The following relation exists between inductance L in henries, capacity C in farads and velocity of light V in miles per second:

$$LC\ (in\ air) = \frac{1}{V^2} \text{ or, } V = \frac{1}{\sqrt{LC}} \tag{17}$$

Thus it will be seen that if either L or C is known, the other may be determined since the velocity of light V is known. If values for L and C are taken which include the inductance inside the conductors, particularly if the conductors are very close together, it would be necessary to assume a velocity of electric propagation somewhat less than that of light. If, on the other hand, the values for L and C external to the conductors are taken, then the above equation is rigidly correct.

In Table C, it was shown that for No. 0000 conductors, 300-in. spacing, the total values of L and C were for a single-phase line,

$L = 0.004779$ henries per mile of circuit.
$C = 0.00000000623$ farads per mile of circuit.

therefore,

$$V = \frac{1}{\sqrt{0.004779 \times 0.00000000623}} =$$

183,000 miles per second (18)

which is less than the speed of light.

If we take the inductance in the air space between the conductors, Formula (2); we arrive at the values,

$L = 0.0046179$ henries per mile of circuit.
$C = 0.00000000623$ farads per mile of circuit.

therefore,

$$V = \frac{1}{\sqrt{0.0046179 \times 0.00000000623}} =$$

186,000 miles per second (19)

which is approximately the speed of light.

Effect of the Ground Upon Charging Currents

Although it is usual to disregard the effect of the earth upon capacitance and corresponding charging current, it may in some cases have an appreciable effect. This effect will be increased as the spacing of conductors relative to the distance to ground (such as in very high voltage circuit) becomes greater. Overhead ground cables bringing the earth potential nearer the conductors also increase the capacitance. Grounded steel towers bringing the earth potential nearer to the conductor at each insulator increase the capacitance somewhat, particularly where corona shields or arcing rings are used and must be charged. Mr. J. P. Jollyman, states that the corona shields, or arcing rings, used on their Pit-Vaca-Dixon lines increase the charging current slightly more than two per cent. He further states that on their 220 Kv. lines, where the spacing between wires is comparable with the distance to ground the capacitance to ground has an appreciable effect on the line constants. This is clearly noticeable by an observation of visual corona on their 220 Kv. line. The bottom wire on the vertical construction has more visual corona than the middle wire, and the middle wire has more than the top wire. In a paper by Mr. R. J. C. Wood, A. I. E. E. transactions, page 725 of August 1922, a test is described which shows that the single phase charging current of one conductor to ground is almost as great as the charging current when the line is charged three phase.

CHAPTER IV

CORONA EFFECT

In 1898, Dr. Chas. F. Scott presented a paper before the A. I. E. E. describing experimental tests (made during several years previous) relating to the energy loss between conductors due to corona effect. These investigations began at the Laboratory at Pittsburgh and were continued at Telluride, Colorado, in conjunction with the engineers of the Telluride Power Company. Preliminary observations were made by Mr. V. G. Converse and were continued in notable measurements by Mr. R. D. Mershon. These investigations were later followed by the work of Professor Ryan, by Mr. R. D. Mershon, Mr. F. W. Peek, Jr., Dr. J. B. Whitehead, Mr. G. Faccioli and others. The electrical profession is particularly indebted to Mr. Peek and Dr. Whitehead for the large amount of both practical and theoretical data which they have presented to the electrical profession on the subject. Mr. Peek developed and presented the empirical formulas which follow, for determining the disruptive critical voltage, the visual critical voltage and the power loss due to corona effect. The following deductions concerning corona have to a large extent been previously presented by Mr. Peek.

Corona, manifesting its presence visually by an electrostatic glow or luminous discharges, and audibly by a hissing sound, was clearly observed and studied in connection with electrostatic machines. It did not become a serious factor to be considered in connection with the design of commercial electrical apparatus until the increasing generator and transmission voltage emphasized its importance.

Although it is usual to think of corona effect only in connection with high-voltage transmission lines, it has received not a little thought of late by the designers of high-voltage generators and motors, notably large, high-voltage turbo generators. By effectively insulating the portion of the conductor embedded in the iron of the armatures of alternating-current machines, particularly with mica, punctures to ground due to corona effect are not likely to occur. However, at the ends of the armature coils (where it is difficult to employ mica for insulating), where air is partially depended upon as an insulating medium between coils and ground, corona may appear. The presence of these corona stresses results in disintegrating and weakening some kinds of insulating materials, causing them to break down after a period of service. This deterioration of insulation may be due to local heating, mechanical vibration or chemical formations in the overstressed air, such as ozone, nitric acid, etc.

Higher voltages are being chosen as an economic means for reducing loss in transmission. These higher voltages may result in corona loss far in excess of the saving in transmission loss due to the adoption of the higher voltages. It is, therefore, pertinent that particular consideration be given to the limitation of corona loss when the choice of conductors is made. This consideration will sometimes make it desirable to take advantage of the higher critical voltage limits of aluminum conductors (with steel reinforced centers) of an equivalent resistance, due to their greater diameter; or it may be desirable to obtain the necessary larger diameter by the use of copper conductors having some form of non-conducting centers or, for still larger diameters, of aluminum conductors having such centers, in order to avoid skin effect. The use of copper conductors having hemp centers has in some instances given mechanical trouble.

The critical voltage at which corona becomes manifest, is not constant for a given line, but is somewhat dependent upon atmospheric conditions. Assuming a line employing conductors just within the critical voltage limitations for the conditions to be met, the corona loss in such a line would be almost negligible during fair weather, but during stormy weather, (particularly during snowstorms) this corona loss would be many times what it is during fair weather. On the other hand, since the storm will usually not appear over the whole length of lines at the same time and since storms occur only at intervals, it may often be economical to allow this loss to reach fairly high values during storms. Fog, sleet, rain and snowstorms lower the critical voltage and increase the losses. The effect of snow is greater than any other weather condition. Increase in temperature or decrease in barometric pressure lowers the voltage at which visual corona starts.

The critical voltage increases with both the diameter of conductors and their distance apart. This sometimes makes it desirable to use aluminum conductors as previously stated. It also increases with the horizontal or vertical arrangement of conductors, due to the fact that the two outside conductors considered as a pair are twice as far apart as are the other pairs. The same general rules apply to stranded conductors as to solid conductors, the actual diameter of the former being considered as the effective diameter of the conductor.

The losses due to corona effect increase very rapidly with increase in voltage after the critical voltage has been reached. A long transmission line having considerable capacitance may deliver a higher voltage than appears at the generator end of the line due to capacitance effect. The corona loss would in this case

be greater per mile at the receiving end than at the sending end of the line.

The magnitude of the losses, as well as the critical voltage, is affected by atmospheric conditions; hence they probably vary with the particular locality and the season of the year. Therefore, for a given locality, a voltage which is normally below the critical point, may at times be above the critical voltage, depending upon changes in the weather.

The material of the conductors does not seem to affect the losses. Sometimes the conductors of new transmission lines, when first placed in service will show visual corona, which may entirely disappear after a few hours or weeks of service. This may be due to scratches, particles of foreign substances, etc., on the conductors which are eliminated after the voltage stress has been kept on the conductors for a short time. Under such conditions the corona loss will also become less as the visual effect disappears.

The loss of power due to corona effect increases with frequency and increases as the square of the excess voltage above a certain critical voltage referred to as the "disruptive critical voltage" e_0. The disruptive critical voltage is that voltage, at which a certain definite and constant potential gradient is reached at the conductor surface. This gradient g_0 is 30 kv. maximum (21.1 kv. effective) per centimeter, or 76.2 kv. maximum (53.6 kv. effective) per inch. These values are based upon an air density at sea level (25°C., 29.92 in. or 76 cm. barometer). This gradient is independent of the size of conductors and their distance apart, but is proportional to the air density, that is to the barometric pressure and the absolute temperatures. It may be considered as the dielectric strength of air. The presence of corona at a certain point of the system shows that a critical electric stress has been exceeded at that point. The corona loss is also proportional to the square root of the conductor radius r and inversely proportional to the square root of the conductor spacing.

The law by which corona losses increase with the voltage does not give a very steep curve, but a rather mild curve following the quadratic law at and above the critical limit. In other words there is no sharp elbow in the curve above which the losses increase very rapidly with the voltage and which could be adopted as the normal operating point of the circuit.

Table C, indicating the voltage limitations due to corona effect, has been worked up from Mr. F. W. Peek's formula as indicated at the bottom of the table. The values in this table are conservative and may in many cases be exceeded. They are the effective e_0 disruptive critical voltage between conductors for fair weather based upon δ values for 25°C. (77°F.) and m_0 values of 0.87 for cable and 0.93 for wire. With these table values, corona loss should not be excessive during storms. If the values of Table C indicate that the conductors contemplated are close to the limit due to corona effect, a careful check should be made by the formula to determine definitely the corona loss for such conductors under storm operating conditions.

F. W. Peek's Corona Formulae

Disruptive critical volts, fair weather (parallel wires)

$$e_0 = 2.302 m_o g_o \delta r \log_{10} \frac{s}{r} \tag{20}$$

effective kv. to neutral,

Visual critical volts, fair weather (parallel wires)

$$e_v = 2.302 m_v g_o \delta r \left(1 + \frac{0.189}{\sqrt{r\delta}}\right) \log_{10} \frac{s}{r} \tag{21}$$

effective kv. to neutral

Power loss (fair weather)

$$P = \frac{390}{\delta}(f + 25)\sqrt{\frac{r}{s}}(e - e_0)^2 10^{-5} \tag{22}$$

kw. per mile of each conductor

Power Loss (Storm).—Storm power loss is higher and can generally be found with fair approximation by assuming e_o = 0.80 times fair weather e_o. It generally works out in practice that the e_o voltage is the highest that should be used on transmission lines (22*A*)

All of the above voltages are to neutral. To find voltages between lines multiply by 1.73 for three-phase, and by 2 for single phase.

Notation

e = Effective applied voltage in kv. to neutral.
(This will vary at different points of the circuit and at different loads. At low loads and long lines of high voltage it may be higher at the receiving end than at the generator end due to inductive capacitance.)

e_o = effective disruptive critical voltage in kv. to neutral. It is the voltage that gives a constant break down gradient for air of 76 kv. maximum per inch, the "elastic limit" at which the air breaks down. Visual corona does not start at the disruptive critical voltage, but at a higher voltage e_v.

e_v = effective visual critical kv. to neutral (voltage at which visual corona starts).

P = power loss in fair weather in kw. per mile of *single* conductor.

$\delta = \frac{17.9b}{459 + t}$. This takes care of the effect of altitude and temperature, (air density). It is 1 at 25°C. (77°F.) and 29.92 in. (76 cm.), barometric pressure.

g_o = 53.6 kv. per inch effective (disruptive gradient of air).

b = barometric pressure in inches.

t = maximum temperature in degrees F.

f = frequency in cycles per second.

m_o = irregularity factor.
= 1 for polished wires.
= 0.98 to 0.93 for roughened or weathered wire.
= 0.87 to 0.83 for cables.

$m_v = m_0$ for wires (1 to 0.93).
= 0.72 for local corona all along cables (7 strands).
= 0.82 for decided corona all along cables (7 strands).

r = radius of conductor in inches.

s = spacing in inches between conductor centers, based upon the assumption of a symmetrical triangular arrangement. For three-phase irregular flat or triangular spacing take $s = \sqrt[3]{ABC}$. For three-phase regular flat spacing take $s = 1.26A$. See also page 19.

According to the theory of Peek, if the conductors were perfectly smooth, no loss would occur until the critical voltage e_v is reached, when the loss should suddenly take a definite value, equal to that calculated by quadratic law, with e_v as the critical voltage in the equation. It should then follow the quadratic law for all higher voltages. Wilkins, however, in the tests on the Pitt River Lines of the Pacific Gas & Electric Co. system, finds that an exponential law agrees more closely with his observations. This may be due to different constants for different portions of the line, as suggested by Peek.

Example.—In order to show the variation in corona loss at different voltages and for different weather conditions, Table E has been calculated for No. 0 stranded copper conductors (105,560 circ. mils, 0.373 in. diameter) and for steel reinforced aluminum conductors (167,800 circ. mils, 0.501 in. diameter) having an equivalent resistance but greater diameter. F. W. Peek's formulas were used and the following assumptions were made:

$$f = 60 \text{ cycles.}$$
$$m_o = 0.87$$
$$m_v = 0.72$$
$$g_o = 53.6$$

$r = 0.186$ in. for copper $= 0.250$ in. for aluminum.
$s = 144$ inches (delta arrangement of conductors).
$b = 28.9$ corresponding to an altitude of 1,000 ft.
$t = 77°$F. δ therefore $= 0.967$.

$\frac{s}{r} = 774$ for copper $= 576$ for aluminum

$$\log_{10} 774 = 2.89 \text{ and } \log_{10} 576 = 2.76$$

$\sqrt{\frac{r}{s}} = 0.036$ for copper and 0.0415 for aluminum.

DISRUPTIVE CRITICAL VOLTAGE—Fair weather

$$e_o = 2.302 m_o g_o \delta r \log_{10} \frac{s}{r} \qquad (20)$$

effective kv. to neutral

For the copper conductors

$e_o = 2.302 \times 0.87 \times 53.6 \times 0.967 \times 0.186 \times 2.89$
$= 55.8$ kv. to neutral (96,500 volts between conductors).

Table *C* gives, by interpolation, the limitation of e_o for above conditions, as 96,500 volts between conductors. To find e_o to neutral for any other altitude or temperatures insert the corresponding values of δ for the altitude and temperature in the formula.

TABLE *D*.—WORKING TABLE—δ (DENSITY) VALUES

Altitude and Temperature Correction Factors

$\delta = \frac{17.9b}{459 + t}$ where b = barometric pressure in inches and t = temperature in degrees F.

Altitude in feet	Barometer		δ values for different temp.		
	In inches	In cm.	0°C. (32°F.)	25°C. (77°F.) *	50°C. (122°F.)
Sea level	30.0	76.2	1.09	1.00	0.925
500	29.45	74.8	1.07	0.985	0.910
1,000	28.90	73.3	1.05	0.967	0.892
1,500	28.30	71.8	1.03	0.947	0.873
2,000	27.80	70.7	1.01	0.932	0.860
2,500	27.25	69.2	0.955	0.912	0.841
3,000	26.80	68.0	0.980	0.897	0.827
4,000	25.75	65.3	0.940	0.860	0.793
5,000	24.70	62.7	0.902	0.827	0.762
6,000	23.90	60.7	0.875	0.800	0.738
7,000	22.95	58.3	0.840	0.770	0.710
8,000	22.05	56.0	0.805	0.738	0.682
9,000	21.30	54.1	0.778	0.712	0.657
10,000	20.50	52.1	0.750	0.687	0.633
12,000	19.00	48.3	0.697	0.637	0.588
14,000	17.55	44.7	0.643	0.588	0.543
15,000	16.90	42.9	0.618	0.566	0.522

* This column contains the values for δ which were used in determining the value e_o in Table *C*. That is, the values for sea level in Table *C* multiplied by these δ values gives the e_o values of the table for the higher altitudes.

For the aluminum conductors

$e_o = 2.302 \times 0.87 \times 53.6 \times 0.967 \times 0.25 \times 2.76$
$= 71.5$ kv. to neutral (123,500 volts between conductors).

Table *C* gives (by interpolation) the limitation for above conditions as 123,500 volts between conductors.

To find e_o to neutral for any other altitude or temperature insert the corresponding value of δ for that altitude and temperature in the formula.

DISRUPTIVE CRITICAL VOLTAGE—Stormy weather

e_o during storm = approximately 80 per cent e_o during fair weather.

For the copper conductors

e_o for storm $= 55.8 \times 0.80 = 44.6$ kv. to neutral or 77,000 volts between conductors.

For the aluminum conductors

e_o for storm $= 71.5 \times 0.80 = 57.2$ kv. to neutral or 98,800 volts between conductors.

VISUAL CRITICAL VOLTAGE—Fair weather

$$e_v = 2.302 m_v g_o \delta r\left(1 + \frac{0.189}{\sqrt{r\delta}}\right) \log_{10} \frac{s}{r} \qquad (21)$$

effective kv. to neutral

For copper conductors

$$e_v = 2.302 \times 0.72 \times 53.6 \times 0.967 \times 0.186\left(1 + \frac{0.189}{0.424}\right) 2.89$$

$= 66.4$ kv. to neutral (115,000 volts between conductors).

To find e_v to neutral for any other altitude and temperature, insert the corresponding values of δ for that altitude and temperature in the formula above.

For the aluminum conductors

$$e_v = 2.302 \times 0.72 \times 53.6 \times 0.967 \times 0.25\left(1 + \frac{0.189}{0.492}\right) 2.76$$

$= 82$ kv. to neutral (141,500 volts between conductors).

To find e_v to neutral for any other altitude and temperature, insert the corresponding values of δ for that altitude and temperature in the formula above.

POWER LOSS

$$P = \frac{390}{\delta}(f + 25)\sqrt{\frac{r}{s}}(e - e_o)^2\, 10^{-5} \qquad (22)$$

kw. per mile of each conductor

The corona power loss corresponding to various conditions for the above circuit has been calculated by formulae (22) and (22*A*). They are given in Table *E*. However, in order to illustrate the application of the power loss formula the losses for the following conditions are determined below. Assuming that the No. 0 stranded copper conductors will be operated at 105 kv. between conductors (60.7 kv. to neutral).

For fair weather—Maximum temperature 50°C. (122°F.)—$e_o = 51.3$ *kv.*

$$P = \frac{390}{\delta}(f + 25)\sqrt{\frac{r}{s}}(e - e_o)^2\, 10^{-5} \qquad (22)$$

kw. per mile of each conductor

$$P = \frac{390}{0.892}(60 + 25) \times 0.036(60.7 - 51.3)^2 10^{-5}$$

$= 1.2$ kw. per mile of each conductor or 3.6 kw. per mile for three conductors.

For stormy weather—Maximum temperature 25°C. (77°F.)—$e_o = 55.8 \times 0.8 = 44.6$ *kv.*

$$P = \frac{390}{0.967}(60 + 25) \times 0.036(60.7 - 44.6)^2 10^{-5} \qquad (22A)$$

$= 3.2$ kw. per mile of each conductor of 9.6 kw. per mile for three conductors.

By applying formula (20) to the above case it develops that the fair weather values of e_o are for 25°C. (77°F.) 96,500 kv. and for 50°C. (122°F.) 88,800 kv. between conductors. Table *C* values for 25°C. (77°F.) confirm this.

Table *E* values for corona loss indicate that No. 0 copper conductors can, with 144-in. delta arrangement of conductors and 1,000 ft. elevation be used at line volt-

TABLE C.—APPROXIMATE VOLTAGE LIMITATIONS RESULTING FROM CORONA

STRANDED COPPER CONDUCTORS

B & S No. and Circular Mils	Diameter in Inches	Elevation in Feet	Limit in kilovolts between conductors 3 phase for various spacings x											
			3 Ft.	4 Ft.	5 Ft.	6 Ft.	7 Ft.	8 Ft.	9 Ft.	11 Ft.	13 Ft	15 Ft	19 Ft.	25 Ft.
4	.232	Sea level	54	56	58	60	62	63	64	66	67	69	71	73
		1000	52	54	56	58	60	61	62	64	65	67	69	71
		2000	50	52	54	56	58	59	60	62	63	65	66	68
		4000	46	48	50	51	53	54	55	57	58	59	61	63
		6000	43	45	46	48	49	50	51	52	53	55	56	58
		8000	40	41	43	44	46	46	47	49	49	51	52	54
		10 000	37	38	40	41	42	43	44	45	46	47	48	50
		12 000	34	35	37	38	39	40	40	42	42	44	45	46
		14 000	32	33	34	35	36	37	37	39	39	40	42	43
3	260	Sea level	59	62	64	66	68	69	70	72	74	76	78	81
		1000	57	60	62	64	66	67	68	70	72	74	76	79
		2000	55	58	60	62	63	64	65	67	69	71	73	76
		4000	51	53	55	57	58	59	60	62	64	65	67	70
		6000	47	49	51	53	54	55	56	57	59	61	62	64
		8000	43	46	47	49	50	51	51	53	54	56	57	60
		10 000	40	42	44	45	46	47	48	49	51	52	53	55
		12,000	37	39	40	42	43	44	44	46	47	48	49	51
		14 000	34	36	37	39	40	40	41	42	43	45	46	47
2	.292	Sea level	65	68	71	73	75	77	78	80	82	84	87	90
		1000	63	66	69	71	73	75	76	78	79	81	84	87
		2000	61	64	66	68	70	72	73	75	76	78	81	84
		4000	56	58	61	63	65	66	67	69	70	72	75	77
		6000	52	54	57	58	60	61	62	64	65	67	69	72
		8000	48	50	52	54	55	57	57	59	60	62	64	66
		10 000	44	46	49	50	51	53	53	55	56	57	60	62
		12 000	41	43	45	46	47	49	49	51	52	53	55	57
		14 000	38	40	42	43	44	45	46	47	48	49	51	53
1	332	Sea level	72	76	79	81	83	85	87	89	91	93	96	100
		1000	70	73	77	78	80	82	84	86	88	90	93	97
		2000	67	71	74	76	77	79	81	83	85	87	90	93
		4000	62	65	68	69	71	73	75	77	78	80	82	86
		6000	57	60	63	65	66	68	69	71	73	74	77	80
		8000	53	56	58	60	61	62	64	65	67	68	71	74
		10 000	49	52	54	55	57	58	60	61	62	64	66	68
		12 000	45	48	50	51	52	54	55	56	58	59	61	63
		14 000	42	44	46	47	49	50	51	52	53	54	56	59
0	.373	Sea level	79	83	87	89	92	94	96	98	101	103	107	111
		1000	77	80	84	86	89	91	93	95	98	100	104	107
		2000	74	77	81	83	86	88	89	91	94	96	100	104
		4000	68	71	75	77	79	81	82	84	86	88	92	95
		6000	63	66	69	71	73	75	76	78	81	82	85	89
		8000	58	61	64	66	68	69	71	72	74	76	79	82
		10 000	54	57	60	61	63	64	66	67	69	70	73	76
		12.000	50	52	55	56	58	59	61	62	64	65	68	70
		14,000	46	49	51	52	54	55	56	57	59	60	63	65
00	.418	Sea level	87	91	95	98	101	103	105	109	111	114	118	122
		1000	84	88	92	95	98	100	102	105	107	110	114	118
		2000	81	85	88	91	94	96	98	102	104	107	110	114
		4000	75	78	82	84	87	89	90	94	95	98	101	105
		6000	69	73	76	78	80	82	82	87	89	91	94	97
		8000	64	67	70	72	74	76	77	80	82	84	87	90
		10 000	59	62	65	67	69	71	72	75	76	78	81	84
		12 000	55	58	60	62	64	65	65	69	70	72	75	77
		14,000	51	53	56	57	59	61	62	64	65	67	69	71
000	.470	Sea level	95	101	105	108	112	114	116	120	123	125	130	135
		1000	92	98	102	104	108	110	112	116	119	121	126	131
		2000	89	94	98	101	104	106	108	112	115	116	121	126
		4000	81	87	90	93	96	98	100	103	106	108	112	116
		6000	76	80	84	86	89	91	92	96	98	100	104	108
		8000	70	74	77	80	83	84	85	88	90	92	96	99
		10,000	65	69	72	74	77	78	79	82	84	86	89	93
		12,000	60	64	67	68	71	72	73	76	78	79	82	85
		14 000	56	59	61	63	66	67	68	70	72	73	76	79
0000	528	Sea level	104	111	115	119	123	125	128	132	136	139	144	150
		1000	101	107	111	115	119	121	124	128	132	134	139	145
		2000	97	103	107	111	115	117	120	123	127	130	134	140
		4000	89	95	99	102	106	107	110	113	117	119	124	129
		6000	83	88	92	95	98	100	102	105	108	111	115	120
		8000	77	81	85	88	91	92	95	97	100	103	106	110
		10.000	71	76	79	81	84	86	88	91	93	95	99	103
		12 000	66	70	73	75	78	79	81	84	86	88	91	95
		14 000	61	65	67	70	72	73	75	77	80	82	84	88

B & S No. and Circular Mils	Diameter in Inches	Elevation in Feet	Limit in kilovolts between conductors 3 phase for various spacings x											
			3 Ft.	4 Ft.	5 Ft	6 Ft.	7 Ft	8 Ft.	9 Ft.	11 Ft.	13 Ft.	15 Ft	19 Ft.	25 Ft.
250 000	.575	Sea level	112	118	124	128	131	134	137	142	145	149	155	160
		1000	109	114	120	124	127	130	132	137	140	144	150	155
		2000	104	110	116	119	122	125	128	132	135	139	145	149
		4000	96	102	107	110	113	115	118	122	125	128	133	138
		6000	89	94	99	102	105	107	110	113	116	119	124	128
		8000	83	87	91	94	96	98	101	105	107	110	114	118
		10,000	77	81	85	88	90	92	94	97	99	102	106	110
		12 000	71	75	79	81	83	85	87	90	92	94	98	102
		14 000	66	69	73	75	77	79	80	83	85	87	91	94
300 000	630	Sea level	120	128	132	138	142	145	148	153	158	161	167	174
		1000	116	124	128	134	138	140	143	148	153	156	162	168
		2000	112	119	123	129	132	135	138	143	148	150	156	162
		4000	103	110	113	119	122	125	127	132	136	139	143	150
		6000	96	102	105	110	114	116	118	122	126	129	133	139
		8000	88	94	97	102	105	107	109	113	116	118	123	128
		10 000	82	88	90	95	97	99	102	105	108	110	114	119
		12 000	76	81	84	88	90	92	94	97	100	102	106	110
		14 000	70	75	77	81	83	85	87	90	93	95	98	102
350 000	681	Sea level	127	135	141	146	151	155	158	163	167	171	178	186
		1000	123	131	136	141	146	150	153	158	162	165	172	180
		2000	119	126	131	136	141	145	148	152	156	160	166	174
		4000	109	116	121	125	130	133	136	140	144	147	153	160
		6000	101	108	113	117	121	124	126	130	134	137	142	148
		8000	93	100	104	107	111	114	117	120	123	126	131	137
		10 000	87	92	96	100	103	106	109	112	115	117	122	127
		12 000	81	86	89	93	96	98	100	103	106	109	113	118
		14 000	75	79	82	86	89	91	93	96	98	101	105	109
400 000	.728	Sea level	135	143	149	155	160	163	166	172	177	182	189	197
		1000	131	139	144	150	155	158	161	166	171	176	183	191
		2000	126	133	139	145	149	152	155	161	165	170	176	184
		4000	116	123	128	133	138	140	143	148	152	157	163	169
		6000	108	114	119	124	128	130	133	138	142	146	151	157
		8000	99	105	110	114	118	120	122	127	130	134	139	145
		10 000	92	98	102	106	110	112	114	118	122	125	129	135
		12 000	86	91	95	98	102	103	106	109	112	116	120	125
		14 000	79	84	87	91	94	96	97	101	104	107	111	116
450 000	772	Sea level	141	150	157	162	167	171	175	181	187	191	198	207
		1000	136	145	152	157	162	166	169	175	181	185	192	200
		2000	132	140	146	151	156	160	163	169	174	178	185	193
		4000	121	129	135	139	143	147	151	156	161	164	170	178
		6000	112	120	125	129	133	137	140	145	149	153	158	165
		8000	104	111	116	119	123	126	129	133	138	141	146	153
		10 000	97	103	108	111	115	117	120	124	128	131	136	142
		12 000	89	95	100	103	106	109	111	115	119	121	126	132
		14 000	83	88	92	95	98	101	103	106	110	112	116	121
500 000	816	Sea level	146	156	163	170	174	179	183	189	195	199	207	216
		1000	141	151	158	164	169	173	177	183	189	193	200	209
		2000	136	146	152	158	163	167	171	176	182	186	193	202
		4000	125	134	140	146	150	154	158	162	168	171	178	186
		6000	117	125	130	136	139	143	146	151	156	159	166	173
		8000	108	115	120	125	128	132	135	139	144	147	153	159
		10 000	100	107	112	117	119	123	126	129	134	137	142	148
		12 000	93	99	103	108	110	114	116	120	124	126	131	137
		14 000	85	91	96	100	102	105	107	111	114	117	121	127
750 000	998	Sea level	172	183	192	200	205	211	216	224	230	236	246	257
		1000	166	177	186	193	198	204	209	216	223	228	238	248
		2000	160	171	180	187	191	197	202	209	215	220	230	240
		4000	148	157	165	172	176	181	186	193	198	203	212	221
		6000	137	146	153	160	164	168	173	179	184	188	196	206
		8000	127	135	141	148	151	155	160	165	170	174	181	190
		10 000	118	126	132	137	141	145	148	154	158	162	169	176
		12 000	109	116	122	127	130	134	137	142	146	150	156	163
		14 000	101	107	113	117	120	124	127	131	135	139	145	150
1 000 000	1.152	Sea level	192	205	216	224	231	237	243	252	260	267	277	290
		1000	186	199	209	217	223	229	235	244	252	258	268	280
		2000	179	191	202	209	215	221	227	235	242	249	258	271
		4000	165	176	185	193	198	204	209	217	224	230	[illegible]	250
		6000	153	164	173	179	185	190	194	202	208	214	222	232
		8000	142	151	159	165	170	175	180	186	192	197	205	214
		10 000	132	141	148	154	159	163	167	173	178	183	190	199
		12 000	122	130	137	142	147	151	154	160	165	169	176	185
		14 000	113	120	127	132	136	139	143	148	153	157	163	170

SOLID COPPER CONDUCTORS

B & S No.	Diameter in Inches	Elevation in Feet	3 Ft.	4 Ft.	5 Ft.	6 Ft.	7 Ft.	8 Ft.	9 Ft.	11 Ft.	13 Ft.	15 Ft.	19 Ft.	25 Ft.
4	204	Sea level	51	54	56	58	59	60	61	63	64	65	68	70
		1000	49	52	54	56	57	58	59	61	62	63	66	68
		2000	47	50	52	54	55	56	57	59	60	61	63	65
		4000	44	46	48	50	51	51	52	54	55	56	58	60
		6000	41	43	45	46	47	48	49	50	51	52	54	56
		8000	37	40	41	42	43	44	45	46	47	48	50	51
		10,000	35	37	38	40	40	41	42	43	44	44	46	48
		12 000	32	34	35	37	37	38	39	40	40	41	43	44
		14 000	30	32	33	34	35	35	36	37	37	38	40	41
3	229	Sea level	57	60	63	64	65	67	68	70	71	73	75	78
		1000	55	58	61	62	63	65	66	68	69	71	73	75
		2000	53	56	59	60	61	62	63	65	66	68	70	73
		4000	49	51	54	55	56	57	58	60	61	63	64	67
		6000	45	48	50	51	52	53	54	56	57	58	60	62
		8000	42	44	46	47	48	49	50	51	52	54	55	57
		10 000	39	41	43	44	44	46	46	48	49	50	51	53
		12 000	36	38	40	40	41	42	43	44	45	46	47	49
		14 000	33	35	37	37	38	39	40	41	42	43	44	46
2	258	Sea level	62	66	68	70	72	73	75	77	79	80	83	86
		1000	60	64	66	68	70	71	73	75	76	77	80	83
		2000	58	61	63	65	67	68	70	72	74	75	78	80
		4000	53	57	58	60	62	63	64	66	68	69	71	74
		6000	49	52	54	56	57	58	60	61	63	64	66	69
		8000	45	48	50	51	53	54	55	57	58	59	61	63
		10 000	42	45	46	48	49	50	51	53	54	55	57	59
		12 000	39	42	43	44	45	46	47	49	50	51	53	54
		14 000	36	39	40	41	42	43	44	45	46	47	49	50
1	289	Sea level	69	72	75	77	79	81	83	85	87	89	92	95
		1000	66	69	72	74	76	78	80	82	84	86	89	92
		2000	64	67	70	72	74	76	77	79	81	83	86	89
		4000	59	62	64	66	68	69	71	73	75	76	79	81
		6000	55	57	60	61	63	65	66	68	69	71	73	76
		8000	51	53	55	57	58	60	61	63	64	65	68	70
		10 000	47	49	51	53	54	55	57	58	60	61	63	65
		12 000	44	45	47	49	50	51	52	54	55	56	58	60
		14 000	40	42	44	45	46	47	49	50	51	52	54	56

B & S No.	Diameter in Inches	Elevation in Feet	3 Ft.	4 Ft.	5 Ft.	6 Ft.	7 Ft.	8 Ft.	9 Ft.	11 Ft.	13 Ft.	15 Ft.	19 Ft.	25 Ft.
0	325	Sea level	75	79	82	85	87	89	91	94	96	98	102	105
		1000	72	76	79	82	84	86	88	91	93	95	98	102
		2000	70	74	76	79	81	83	85	88	90	92	95	98
		4000	64	68	70	73	75	76	78	81	82	84	88	90
		6000	60	63	65	68	69	71	73	75	76	78	82	84
		8000	55	58	60	62	64	66	67	69	71	72	75	77
		10 000	51	54	56	58	60	61	62	64	66	67	69	72
		12 000	47	50	52	54	55	56	58	60	61	62	65	67
		14 000	44	46	48	50	51	52	53	55	56	58	60	61
00	365	Sea level	83	88	91	94	96	98	100	104	106	109	112	116
		1000	80	85	88	91	93	94	97	100	103	105	108	112
		2000	77	82	85	88	90	92	93	97	99	102	104	108
		4000	71	75	78	81	82	84	86	89	91	94	96	100
		6000	66	70	73	75	77	78	80	83	85	87	89	92
		8000	61	65	67	69	71	72	74	76	78	80	82	85
		10 000	57	60	62	64	66	67	68	71	72	75	77	79
		12 000	53	56	58	59	61	62	63	66	67	69	71	73
		14 000	48	51	53	55	56	57	59	61	62	64	66	68
000	.410	Sea level	91	96	100	103	106	109	111	114	117	120	124	128
		1000	88	93	97	100	102	105	107	110	113	116	120	124
		2000	85	90	93	96	99	102	103	106	109	112	116	120
		4000	78	82	86	88	91	93	95	98	100	103	107	110
		6000	73	77	80	82	84	87	89	91	93	96	99	102
		8000	67	71	74	76	78	80	82	84	86	88	91	94
		10 000	62	66	69	71	73	75	76	78	80	82	85	88
		12 000	58	61	63	65	67	69	70	72	74	76	79	81
		14 000	53	56	59	61	62	64	65	67	68	70	73	75
0000	460	Sea level	100	106	110	114	117	120	122	126	129	132	137	142
		1000	97	102	106	110	113	116	118	122	125	127	132	137
		2000	93	99	103	106	109	112	114	118	120	123	128	133
		4000	86	91	95	98	100	103	105	108	111	113	118	122
		6000	80	85	88	91	93	96	97	101	103	105	109	113
		8000	74	78	81	84	86	88	90	93	95	97	101	105
		10 000	69	72	75	78	80	82	84	86	88	91	94	97
		12 000	63	67	70	72	74	76	77	80	82	84	87	90
		14 000	59	62	64	67	69	70	71	74	76	77	80	83

x For single phase or 2 phase multiply the 3 phase values by 1.16. The above are the disruptive critical voltage values for fair weather based upon a temperature of 25° C. (77° F.) and values for M_0 of 0.87 for stranded and 0.93 for solid conductors. Derived by Peek's formula: Kilovolts to neutral $= 2.302\, M_0\, G_0\, \delta\, R \log_{10} \frac{S}{R}$, where $G_0 = 53.6$ Kilovolts per inch; S = Spacing in inches; R = Radius of conductor in inches; $\delta = \frac{17.9\, B}{459 + T}$; T = Temperature in degrees F.; B = Barometer pressure in inches.

ages as high as 100,000 volts without excessive corona loss during stormy weather. At 100,000 volts and assuming a 25°C. (77°F.) temperature during fair weather and storm conditions, the corona losses would be 0.1 kw. per mile for fair weather and 6.5 kw. per mile for stormy weather. If the transmission is single circuit 100 miles long and without branches, has an average altitude of 1,000 ft. and the storm condition existed throughout the length of the circuit, the power loss due to corona would be 6.5 $\times$ 100 or 650 kw. The capacity of such a circuit at 100,000 volts would be roughly 15,000 kw. at 10 per cent I^2R loss. The storm corona loss therefore would represent 650/15,000 or 4.3 per cent. This, in addition to 10 per cent I^2R loss, would represent approximately 14 per cent loss in transmission during the storm conditions.

In the above case it would probably be considered good engineering (so far as corona loss is concerned) to operate the No. 0 copper conductors at as high a line voltage as 100,000 volts. If, however, for other reasons, 120,000 is selected as the desirable operating voltage, then either a large diameter copper conductor or an aluminum conductor having a greater diameter but an equivalent conductivity to that of the No. 0 copper conductor should be selected.

The Irregularity Factor

An investigation by Mr. Peek has shown that in new cables up to 2.5 cm. (1 in.) in diameter, the irregularity factor is approximately the same for 19-, 37- and 61-strand cables (concentric lay). Under the above conditions

$$M_o = .8 \text{ to } .87$$

depending upon the surface condition of the cable and probably improves somewhat with use as the abrasions become oxidized away. For new cables it is generally .8. With special types of cables, values as low as .70 were obtained. Seven-strand cables of the large size are undesirable since the large wires become mutilated and the irregularity factor becomes low.

Although in the above investigation with 19, 37 and 61 strands there was no great difference in the loss, the measurements were slightly in favor of 37 strands for the one-inch diameter conductor. It seems inadvisable to use a stranding that would make the individual conductors too small compared with the cable diameter.

While the diameter of the conductor has a greater influence on the losses than any other factor, it is important that in special conductors the diameter is not increased at the expense of surface irregularities or there may be no particular gain. The surface irregularity is taken care of by the irregularity factor M_o. It is particularly important to avoid projecting irregularities. Strands of too small a diameter compared to the diameter of the conductor are also not desirable. The irregularity factors given apply to the standard concentric-lay cables. Where a quite special conductor has been developed the irregularity factor may be quite different.

The accompanying photograph illustrating corona on an experimental line is published with the kind permission of F. W. Peek, Jr.

Corona at 230 kv. 1.19 cm. diameter, 0.47 ft. cable, 310 cm. 10 ft. spacing.

With further reference to Mr. Wilkins' work on corona on the Pit River Lines of the Pacific Gas & Electric Co., Mr. Jollyman has drawn the following conclusions:

Corona loss follows exponential laws, both below and above the "critical voltage."

Factors not heretofore considered important such as capacity to earth and configuration, have a marked effect on corona loss.

Aluminum has certain characteristics with respect to corona not possessed by copper.

Losses below critical voltage are large enough to be of commercial importance.

Since the formulas pertaining to corona effect are to some extent worked up from test data they may be slightly changed from time to time. In case the problem at hand seems vitally near the critical point it will be well to consult the latest literature at that time as an additional check on the work.

TABLE *E*.—COMPARISON OF CORONA LOSS

For No. 0 Stranded Copper Conductors 105,560 Circ. Mils (Diameter 0.373 In.) and Equivalent Aluminum Conductors 167,800 Circ. Mils (Diameter 0.501 In.) Conductor Spacing (s) Delta = 144 In. Altitude 1,000 Ft.—Barometer 28.9 In. Calculated from Formula (22)

Kilovolts		Corona loss in kw. per mile for three conductors at 60 cycles											
		Fair weather—(Formula 22)						Stormy weather—(Formula 22-A)					
		No. 0 copper radius 0.186 in.			Aluminum radius 0.25 in.			No. 0 copper radius 0.186 in.			Aluminum radius 0.25 in.		
Between conductors	To neutral	0°C. 32°F. $\delta=1.05$ $e_0=60.5$	25°C. 77°F. $\delta=0.967$ $e_0=55.7$	50°C. 122°F. $\delta=0.892$ $e_0=51.3$	0°C. 32°F. $\delta=1.05$ $e_0=77.5$	25°C. 77°F. $\delta=0.967$ $e_0=71.5$	50°C. 122°F. $\delta=0.892$ $e_0=66.0$	0°C. 32°F. $\delta=1.05$ $e_0=48.4$	25°C. 77°F. $\delta=0.967$ $e_0=44.5$	50°C. 122°F. $\delta=0.892$ $e_0=41.0$	0°C. 32°F. $\delta=1.05$ $e_0=62$	25°C. 77°F. $\delta=0.967$ $e_0=57.2$	50°C. 122°F. $\delta=0.892$ $e_0=52.7$
100	57.8	0.0	0.1	0.2	0	0	0	0.3	6.5	11.3	0	0	1.1
110	63.5	0.3	2.3	6.0	0	0	0	7.8	13.3	20.3	0	1.7	4.6
120	69.2	2.6	6.7	12.8	0	0	0.4	14.8	22.6	32.0	2.0	6.2	12.6
130	75.1	7.25	13.9	22.6	0.0	0.5	3.8	24.4	34.6	46.5	6.7	13.7	23.2
140	80.8	13.8	23.3	34.8	0.3	3.7	10.1	35.8	48.7	63.7	13.9	23.8	36.4
150	86.7	22.4	35.5	50.2	3.3	9.9	19.7	50.2	66.	84.	24.	37.2	53.3
160	92.4	35.0	49.8	67.7	8.7	18.7	32.2	66.	85.	106.	36.	53.	73.
180	104.8	66.0	89.0	115.0	29.3	47.3	69.5	108.	135.	163.	72.	96.	125.

NOTE.—At 25 cycles the losses would be $\frac{f_1 + 25}{f + 25} = \frac{25 + .25}{60 + 25} = \frac{50}{85}$ times the above table values. For conductors in a row (flat spacing) the coronal loss would be reduced below the values for delta or triangular arrangement. For the higher voltages in the above table the conductor spacings would, in an actual installation, be greater than 144 in. (upon which basis the table values are given) thus giving actually less corona loss for the higher voltages than indicated by the table values.

EQUIVALENT SPACING IN CALCULATING CORONA LOSS

When the conductors are not spaced in an equilateral triangle, but as is often the case in practice, are spaced symmetrically in a vertical or a horizontal plane, or in an irregular triangle, the exact calculation for corona loss becomes quite complicated. F. W. Peek, Jr. shows an example of such a calculation on page 234 of his book "Dielectric Phenomena in High Voltage Engineering," published by the McGraw Hill Book Company, Inc. All persons having corona calculations to make should be equipped with a copy of Mr. Peek's book. He refers to spacing as follows:

"When conductors are not spaced in an equilateral triangle, but, as is often the case in practice, symmetrically in a plane, corona will start at a lower voltage on the center conductor, where the stress is greatest, than on the outside conductors. The actual critical voltage for the center conductor will be approximately 4 per cent lower, and for the two outer conductors, 6 per cent higher, than the value for the same s, in the equilateral triangle arrangement. If a triangle is used where there is considerable difference between s_1, s_2 and s_3, an exact calculation of the stress should be made."

Unless the line is to be operated close to or slightly above the critical corona voltage the "equivalent spacing" may be used with but unimportant error. There are so many variables such as altitude and atmospheric conditions along the line as seldom to warrant the complication of an exact calculation.

CHAPTER V

DETERMINATION OF VOLTAGE—FREQUENCY

FREQUENCY DETERMINATION

Cost of Transformers.—Sixty-cycle transformers cost approximately 30 to 40 per cent less than 25-cycle transformers; or stated another way, 25-cycle transformers cost approximately 40 to 66 per cent more than 60-cycle transformers. The saving in first cost may vary between $1.50 and $2.50 per kv.a. in favor of 60 cycles. Assuming that the total kv.a. of transformer capacity connected to a transmission circuit is 2.5 times the kv.a. transmitted over the circuit, the saving in favor of 60-cycle transformers would be $3.75 to $6.25 or an average of $5.00 per kv.a. transmitted. Assuming 20,000 kv.a. to be transmitted, the saving in cost at $5.00 per kv.a. will be $100,000 in favor of 60-cycle transformers. The actual difference in cost will depend upon the type of the transformers, that is, whether water or self-cooled and also upon their average capacity. The difference in cost will be greater for the self-cooled type and for the smaller capacities.

Weight and Space of Transformers.—The less weight of 60-cycle transformers makes them easier to handle and they require less space for installation.

Higher Reactance.—Inductive reactance at 60 cycles is 2.4 times its value at 25 cycles. This tends to produce poorer voltage regulation of the circuit. Higher reactance has one advantage for the larger systems in that it tends to limit short-circuit currents and thus assists the circuit opening devices to function properly. By virtue of the higher reactance it might be possible in some cases to obtain sufficient reactance in the transformers without the addition of current limiting reactance coils.

Efficiency.—The efficiency of 60-cycle transformers is usually 0.25 to 0.50 per cent higher than for 25-cycle transformers.

Charging Current.—At 25 cycles both the charging current and the reactance are approximately 42 per cent of their values for 60 cycles. This tends to give better regulation and usually higher efficiency in transmission. On the other hand, the higher transmission efficiency may be offset by the slightly lower efficiency of 25-cycle transformers. In cases of very long circuits (particularly if the circuits are in duplicate and both in service) or of transmission systems embracing many miles of high tension mains and feeders, the charging currents may be so great as to limit the choice in transmission voltage. On the other hand large charging currents may be permitted, provided under excited synchronous motors are used at various parts of the transmission system for partially neutralizing this charging current and for maintaining constant voltage.

Inductive Disturbances.—Lightning, switching and other phenomena cause disturbances on conductors of transmission circuits. The frequency of these disturbances is independent of that impressed on the system. After the removal of the disturbing influence they oscillate with the natural frequency of the line.

The natural frequency of the line is far above commercial frequencies but, if the transmission line is long, there may be some odd harmonic present in the fundamental impressed frequency which corresponds with the natural period of the line. This might tend to produce an unstable condition or resonance. This condition is somewhat less likely to occur at 25 cycles.

Summary.—Although there are a number of large 25-cycle transmission systems in operation, they were mostly installed before the design of 60-cycle converting apparatus and electric light systems had reached their present state of perfection. Unless it is desirable to parallel with an existing 25-cycle system located in adjoining territory without the introduction of frequency changers, it isnow quite general practice to choose the frequency of 60 cycles.*

VOLTAGE DETERMINATION

From a purely economic consideration of the conductors themselves, Kelvin's law for determining the most economical size of conductors would apply. Kelvin's law may be expressed as follows:

"The most economical section of a conductor is that which makes the annual cost of the I^2R losses equal to the annual interest on the capital cost of the conducting material, plus the necessary annual allowance for depreciation." That is, the economical size of conductor for a given transmission will depend upon the cost of the conducting material and the cost of power wasted in transmission losses. The law of maximum economy may be stated as follows: "The annual cost of the energy wasted per mile of the transmission circuit added to the annual allowance per mile for depreciation and interest on first cost, shall be a minimum."

Attempts have been made to determine by mathematical expression the most economical transmission voltage, all factors having been taken into account. There are so many diverse factors entering into such a treatment as to make such an expression

* For a complete discussion of this subject see a paper by D. B. Rushmore before the Schenectady section A. I. E. E., May 17, 1912, on Frequency and an article by B. G. Lamme on "The Technical Story of the Frequencies" in the *Journal*, June, 1918, p. 230.

complicated, difficult and unsatisfactory. There are many points requiring careful investigation, not embraced by Kelvin's law, before the proper transmission voltage can be determined. Some of these points are given below.

TABLE E-1.—WEIGHT OF BARE COPPER CONDUCTORS

B & S No.	Area in circular mils	Weight in pounds, Per 1,000 feet of circuit, Number of conductors: One	Two	Three	Per mile of circuit, Number of conductors: One	Two	Three
	2,000,000	6,180	12,360	18,540	32,630	65,260	97,890
	1,900,000	5,870	11,740	17,610	30,994	61,988	92,982
	1,800,000	5,560	11,120	16,680	29,357	58,714	88,071
	1,700,000	5,250	10,500	15,750	27,720	55,440	83,160
	1,600,000	4,940	9,880	14,820	26,083	52,166	78,249
	1,500,000	4,630	9,260	13,890	24,446	48,892	73,338
	1,400,000	4,320	8,640	12,960	22,810	45,620	68,430
	1,300,000	4,010	8,020	12,030	21,173	42,346	63,519
	1,200,000	3,710	7,420	11,130	19,589	39,178	58,767
	1,100,000	3,400	6,800	10,200	17,952	35,904	53,856
	1,000,000	3,090	6,180	9,270	16,315	32,630	48,945
	950,000	2,930	5,860	8,790	15,470	30,940	46,410
	900,000	2,780	5,560	8,340	14,678	29,356	44,034
	850,000	2,620	5,240	7,860	13,834	27,668	41,502
	800,000	2,470	4,940	7,410	13,042	26,084	39,126
	750,000	2,320	4,640	6,960	12,250	24,500	36,750
	700,000	2,160	4,320	6,480	11,405	22,810	34,215
	650,000	2,010	4,020	6,030	10,613	21,226	31,839
	600,000	1,850	3,700	5,550	9,768	19,536	29,304
	550,000	1,700	3,400	5,100	8,976	17,952	26,928
	500,000	1,540	3,080	4,620	8,131	16,262	24,393
	450,000	1,390	2,780	4,170	7,339	14,678	22,017
	400,000	1,240	2,480	3,720	6,547	13,094	19,641
	350,000	1,080	2,160	3,240	5,702	11,404	17,106
	300,000	926	1,852	2,778	4,889	9,778	14,667
	250,000	772	1,544	2,316	4,076	8,152	12,228
0000	212,000	653	1,306	1,959	3,448	6,896	10,344
000	168,000	518	1,036	1,554	2,735	5,470	8,205
00	133,000	411	822	1,233	2,170	4,340	6,510
0	106,000	326	652	978	1,721	3,442	5,163
1	83,700	258	516	774	1,362	2,724	4,086
2	66,400	205	410	615	1,082	2,164	3,246
3	52,600	163	326	489	861	1,722	2,583
4	41,700	129	258	387	681	1,362	2,043
5	33,100	102	204	306	539	1,078	1,617
6	26,300	81	162	243	428	856	1,284
7	20,800	64	128	192	338	676	1,014
8	16,500	51	102	153	269	538	807

Cost of Conductors.—For a given percentage energy loss in transmission, the cross-section and consequently the weight of conductors required by the lower and medium voltage lines (up to approximately 30,000 volts) to transmit a given block of power varies inversely as the square of the transmission voltage. Thus if this voltage is doubled, the weight of the conductors will be reduced to one-fourth with approximately a corresponding reduction in their cost. This saving in conducting material for a given energy loss in transmisson becomes less as the higher voltages are reached, becoming increasingly less as voltages go higher. This is for the reason that for the higher voltages at least two other sources of losses, leakage over insulators and the escape of energy through the air between the conductors (known as "corona") appear. In addition to these two losses, the charging current, which increases as the transmission voltage goes higher, may either increase or decrease the current in the circuit depending upon the power-factor of the load current and the relative amount of the leading and lagging components of the current in the circuit. Any change in the current of the circuit will consequently be accompanied by a corresponding change in the I^2R loss. In fact, these sources of additional losses may, in some cases of long circuits or extensive systems, materially contribute toward limiting the transmission voltage. The weight of copper conductors, from which their cost may readily be calculated, is given in Table E-1. As an insurance against breakdown, important lines frequently are built with circuits in duplicate. In such cases the cost of conductors for two circuits should not be overlooked.

Table E-1 contains the weights of bare stranded copper cables per 1,000 ft. of circuit, also per mile of circuit. For the purpose of facilitating rapid calculation for any given case, the weights are given corresponding to one, two and three conductors for these two lengths of circuit.

Reduced Electric Surges.—The better insulation necessitated by higher transmission voltages tends to make the circuit more secure against ordinary disturbances. Also the smaller currents resulting with the higher voltages cause less disturbance in the circuit in the case of grounds, short-circuits, switchings, lightning and other disturbances.

Less Reactance Volts Drop.—Since the current corresponding to higher transmission voltages goes down as the voltage goes up, the voltage necessary to overcome the reactance of the circuit will be less, and the percentage reactance volts much less for higher voltages. Thus, if the transmission voltage is doubled, the current will be halved and for the same spacing of conductors the reactance volts drop will be one-half, resulting in one-fourth the percentage of the reactance-volts drop.

Cost of Transformers.—If the transmission voltage exceeds 13,200 volts, banks of step-up transformers will be required of sufficient capacity to transform all of the kv.a. to be transmitted. A still greater capacity of

step-down transformers will be required to reduce the voltage to that suitable for operating motors and lights. In some cases two reductions from the transmission circuit voltage may be required, the first usually reducing to 22,000, 11,000 or 6,600 volts for general distribution and the second reducing from the general distribution voltage to the proper voltage for motors and lights. The net result is that the total capacity in transformers connected to a transmission system employing both step-up and step-down transformers may vary from a minimum of two to a maximum of about four times the kv.a. transmitted over the high-tension circuits. The average condition we will assume as 2.5 times the kv.a. to be transmitted.

The cost of power transformers at the present time for 66,000 volts service will vary between $1.25 to $3.00 for 60-cycle and $2 to $5 per kv.a. for 25-cycle service, depending upon their type and capacity. The total cost per kv.a. of transformers on a system would therefore be represented by approximately 2.5 times the above costs. The present relative costs of transformers for different voltages are given in Table *F*. For instance if the transmission voltage is increased from 33,000 to 66,000 volts the transformers will cost in the neighborhood of 150 ÷ 115 or 31 per cent more than they would cost for 33,000 volts. Knowing the amount of power to be transmitted, an approximate estimate may be made as to the additional cost of the necessary transformers for a higher voltage.

Table *F*.—Present Relative Costs of High Tension Apparatus

Expressed in Per Cent (6,600 Volt Costs Taken as 100 Per Cent)

	6,600 volts	11,000 volts	13,200 volts	16,500 volts	22,000 volts	33,000 volts	44,000 volts	66,000 volts	88,000 volts	110,000 volts	120,000 volts
Transformers	100	102	104	106	108	115	125	150	175	200	225
Switches	100	100	100	100	100	110	115	155	255	420	
Electrolytic arresters	100	151	160	195	205	320	430	640	1,600	1,900	2,400
Insulators	100	135	185	365	430	650	1,250	3,500	5,500	6,500	7,700

Cost of Insulators.—Table *F* values indicate a wide difference in the cost of insulators for the higher voltages; thus the increased cost of 66,000 volt insulators above the cost of 33,000 volt insulators is stated as 3,500 ÷ 650 or 540 per cent.

Cost of Other Apparatus.—The cost of lightning arresters, high-tension circuit breakers and general insulation increase with the voltage. The increased cost of these items, however, may not have sufficient weight to materially influence the selection of the transmission voltage.

Cost of Buildings.—Lower voltage transformers, switching equipment and lightning arresters require less space for installation. If this apparatus is to be placed indoors, the cost of necessary buildings may be less. The amount of real estate required may also be less in case of the lower voltage.

Relative Cost Values.—Table *F* contains relative cost values for different transmission voltages. They indicate approximately the variation, at the present time, in cost of the principal material which is affected by a change in transmission voltage. Cost values are very unstable at present but the table will serve in a general way to indicate comparative costs.

Efficiency.—The efficiency of transformers will be slightly higher for the lower voltages.

Small Customers.—The furnishing of power to small customers at points along the transmission circuits should receive careful consideration. The cost of switching apparatus, lightning arresters and transformers required to permit service being given to such customers will be less for the lower voltage.

Charging Current.—The amount of current required to charge the transmission circuits varies approximately as the transmission voltage. Therefore the charging current, expressed in kv.a. varies approximately as the square of the voltage. Thus the charging current required for a 33,000 volt circuit is approximately one-half and the charging kv.a. one-fourth that of a 66,000 volt circuit.

Summary.—In deciding upon the transmission voltage, careful and full consideration should be given to the present (or probable future) voltage of any neighboring or adjacent systems. There is an increasing tendency to combine generating and transmission systems for purposes of economy, and insurance against breakdown in service. If a possible future consolidation is not kept in mind when selecting the transmission voltage, a voltage may be decided upon which would render it impossible to parallel with a neighboring system, except through connecting transformers. In this case the transformers of the two systems would probably not be interchangeable for service on either system.

If the contemplated transmission system is remote from any existing system, a study of the initial and operating costs should be made corresponding to various sizes of condutors and to various assumed transmission voltages. A suggested tabulation for such comparisons is shown in Table *G*. In this table, it is assumed that 10,000 kv.a. (8,000 kw. at 80 per cent power-factor lagging), is to be transmitted a distance of 10 miles at 60 cycles, three-phase for 10 hours, followed by 2,500 kv.a. (2,000 kw. at 80 per cent power-factor lagging) for 14 hours. Delta spacing is assumed of 3 ft. for the lower two and 4 ft. for the higher two voltages. Raising and lowering transformers will be required of an assumed total capacity of 2.5 × 10,000 or 25,000 kv.a. Conductors of hard drawn stranded copper are employed the resistance of the conductors being taken at a temperature of 25°C. from an old table.

The cost of the pole or tower line, the right of way, buildings and real estate for buildings is not included in this tabulation. Neither is the difference in transformer efficiencies taken into account. The difference in these items will not be sufficient in this case greatly to influence the choice of the transmission voltage, because all of the voltages compared are relatively

TABLE *G*.—FORM OF TABULATION FOR DETERMINING VOLTAGES AND CONDUCTORS

Based on the Transmission of 10,000 Kv.-a. for 10 Miles at 80 Per Cent Power-factor Lagging, 60-cycles, Three-phase

Voltage: Between conductors	Voltage: To neutral	Amperes for 10,000 kv.a.	Conductors: B & S or circ. mils	Conductors: Total weight in pounds	Conductors: Resistance ohms	Total I^2R loss, 10,000 kv.a.: Kw. for 10 hrs.	Total I^2R loss, 10,000 kv.a.: Loss in per cent	Total I^2R loss, 2,500 kv.a.: Kw. for 14 hrs.	Total loss per year in kw.-hours	Voltage drop at full load: Resistance IR in per cent	Voltage drop at full load: Reactance XI in per cent	Voltage drop at full load: Volts drop in per cent	First cost: Conductors at 25 cts per pound	First cost: Transformers 25,000 kv. a.	First cost: High tension switches	First cost: Lightning arresters	First cost: Insulators	First cost: Total	Annual operating cost: Interest on first cost at 6 per cent	Annual operating cost: Depreciation on first cost at 10 per cent	Annual operating cost: I^2R losses at 1 ct. per kw.-hour	Annual operating cost: Total
			500,000	243,930	1.17	430	5.3	27	1,707,470	4.3	21.7	17.5	$60,982	$75,000	$3,000	$1,000	$ 900	$140,882	$8,453	$14,088	$17,075	$39,616
16,500	9,526	350	300,000	146,670	1.96	720	9.0	45	2,857,950	7.2	22.7	20.0	36,670	75,000	3,000	1,000	900	116,570	6,994	11,657	28,580	47,231
			#000	82,050	3.50	1,286	16.1	80	5,102,700	12.9	24.2	25.0	20,512	75,000	3,000	1,000	900	100,412	6,025	10,041	51,027	67,093
			300,000	146,670	1.96	403	5.0	25	1,598,700	4.0	12.8	11.0	36,670	76,500	3,000	1,050	1,200	118,420	7,105	11,842	15,987	34,934
22,000	12,702	262	#000	82,050	3.50	720	9.0	45	2,857,950	7.2	13.6	14.0	20,512	76,500	3,000	1,050	1,200	102,262	6,136	10,226	28,580	44,942
			#0	51,630	5.55	1,143	14.3	71	4,534,760	11.5	14.1	17.5	12,910	76,500	3,000	1,050	1,200	94,660	5,680	9,466	45,348	60,494
			#00	65,100	4.42	406	5.1	25	1,609,650	4.0	6.5	7.0	16,275	82,500	3,300	1,600	1,980	105,655	6,340	10,565	16,097	33,002
33,000	19,053	175	#2	32,460	8.83	811	10.1	50	3,215,650	8.0	6.8	10.5	8,117	82,500	3,300	1,600	1,980	97,497	5,850	9,749	32,156	47,755
			#4	20,430	14.1	1,295	16.2	81	5,140,660	12.9	7.1	14.5	5,107	82,500	3,300	1,600	1,980	94,487	5,670	9,448	51,407	66,525
			#2	32,460	8.83	454	5.7	29	1,805,290	4.6	3.9	6.0	8,117	90,000	3,450	2,200	3,960	107,727	6,463	10,772	18,053	35,288
44,000	25,404	131	#5	16,170	17.8	916	11.4	58	3,639,780	9.1	4.0	9.5	4,040	90,000	3,450	2,200	3,960	103,650	6,219	10,365	36,398	52,982

low. Because of the large amount of power to be transmitted a comparatively short distance, the approximate rule of 1,000 volts per mile for short lines does not hold true for this problem.

Assuming for the sake of argument that the price values given in this form of tabulation are approximately correct for this problem and that there are no neighboring transmission systems, then the problem reduces to cost economics.

Since both the first and operating costs in Table *G* are higher for 16,500 volts than they are for 22,000 volts, it is evident that 16,500 volts is economically too low a voltage.

In the consideration of 22,000 volts it will be seen that, of the three sizes of conductors, the largest size (300,000 circ. mils) will be the cheaper in the end. Thus, if No. 000 were selected, the first cost would be $16,159 less than for 300,000 circ. mil conductors, but the operating cost (due to greater loss in transmission) will be approximately $10,000 a year more. For a similar reason No. 0 conductors will be disqualified.

In the consideration of 33,000 volts, No. 00 conductors will be the choice and in the consideration of 44,000 volts, No. 2 conductors will be the choice. The choice then comes down to the following:

Voltage transmission	Conductors	Total cost first	Annual operating cost
22,000	300,000 circ. mils	$118,420	$34,934
33,000	No. 00	105,655	33,002
44,000	No. 2	107,727	35,288

It will thus be seen that a voltage of 33,000 volts and No. 00 conductors are the most economical of those tabulated. The transmission loss will be 5.1 per cent, the reactance 6.5 per cent and the voltage drop 7 per cent at full load. The value assigned as the cost per kw.-hour for power lost in transmission will obviously have great influence in determining the proper economic size of conductors for any given transmission voltage. The cost of the copper will have a relatively greater importance on longer lines. As a matter of fact, a larger size than any of the conductors listed in Table *G* would be still more economical, under the conditions given. There have been numerous mistakes made in under-estimating the ultimate demand for electrical power and consequently adopting too low a transmission voltage. When in doubt the higher voltage will, in the course of time, most likely justify its adoption by reason of future growth not apparent at the time the choice is made.

The design and construction of transformers, circuit breakers, lightning arresters, etc. for a multiplicity of high-tension voltages is expensive. The manufacturers of such apparatus are endeavoring to standardize transmission voltages for the purpose of minimizing the number of designs of high-tension apparatus. This point could with mutual profit be taken up with the manufacturers before any particular voltage is decided upon.

The amount and cost of power to be transmitted is a very important factor in determining the economic transmission voltage. For average conditions isolated from existing transmission lines the voltages shown in Table *H* have been quite generally used. For exceptional cases, exceptional values will be used. For

TABLE H.—COMMON TRANSMISSION VOLTAGES

Length of line	Voltages
1 to 3 miles	550 or 2,200 volts
3 to 5 miles	2,200 or 6,600 volts
5 to 10 miles	6,600 or 13,200 volts
10 to 15 miles	13,200 or 22,000 volts
15 to 20 miles	22,000 or 33,000 volts
20 to 30 miles	33,000 or 44,000 volts
30 to 50 miles	44,000 to 66,000 volts
50 to 75 miles	66,000 or 88,000 volts
75 to 100 miles	88,000 or 110,000 volts
100 to 150 miles	110,000 or 132,000 volts
150 to 250 miles	132,000 or 154,000 volts
250 to 350 miles	154,000 or 220,000 volts

example if 40,000 kv.a. is to be transmitted 20 miles, 66,000 volts or higher might be used. On the other hand if a very small amount of power is to be transmitted, lower voltages would probably be selected.

At the present time the prospects seem bright for the standardization of the following "normal" system voltages.

44,000	132,000
66,000	154,000
88,000	*187,000
110,000	220,000

* The use of 187,000 volts is likely to occur only in case it is found necessary to have a voltage between 154,000 and 220,000 volts.

CHAPTER VI

QUICK ESTIMATING TABLES

For every occasion where a complete calculation of a long distance transmission line is made, there are many where the size of wire needed to transmit a given amount of power economically is required quickly. This knowledge is, moreover, the basis for all transmission line calculations, as all methods of calculating regulation presuppose that the size of wire is known. To determine quickly and with the least possible calculation the approximate size of conductor corresponding to a given I^2R transmission loss for any ordinary voltage or distance, is the function of the quick estimating tables. These tables are based upon old resistance tables which did not include skin effect and upon aluminum equivalents which did not include the iron loss of the steel reinforced strands. The effect of these additional losses being generally small will not seriously effect the accuracy of these quick estimating tables. By including so many transmission voltages it is not intended to indicate that any of them might equally well be selected for a new installation. On the contrary it is very desirable in the consideration of a new installation, to eliminate consideration of some of the voltages now in use. This point will be considered later.

Since both the power-factor of the load, and the charging current of the circuit, as well as any change in the resistance of the conductors, will alter the I^2R loss, it is evident that it is impractical to present tables which will take into account the effect of all of these variables. The accompanying tables do, however, give the percentage I^2R loss corresponding to the two temperatures (25 and 65°C.) ordinarily encountered in practice and the usual load power-factors of unity and 80 per cent lagging, upon which the kv.a. values of the tables are based. The effect, however, of charging current, corona or leakage loss is not taken into account in these table values. The latter two (corona and leakage) are usually small and need not be considered here. The effect of charging current, may, however, with long circuits be material and will be discussed.

The values of kv.a. in these tables are based upon the following percentage I^2R loss in transmission (neglecting the effect of charging current):

	Per Cent Loss at 25°C.	Per Cent Loss at 65°C.
Load at 100 per cent PF..........	8.66	10.0
Load at 80 per cent PF...........	10.8	12.5

These loss values are based upon the power delivered at the end of the circuit as 100 per cent, and not upon the power at the supply end. If raising or lowering transformers are employed, the loss and voltage drop in them will, of course, be in addition to the above.

At first glance, some of these tables may appear to have been carried to extremes of kv.a. values for the conductor sizes. This is because the tables are calculated for 10 per cent loss, (at 100 per cent power-factor and 65°C.) whereas the permissible loss is frequently much less than 10 per cent. As the loss is directly proportional to the load, the permissible loads for a given size wire and distance can be read almost directly for any loss. Thus for a 2 per cent loss the permissible kv.a. will be two-tenths the table values. Conversely, the size of wire to carry a given kv.a. load at 2 per cent loss will be the same a will carry five ($10 \div 2$) times the kv.a. at 10 per cent loss. In other words to find the size of wire to carry a given kv.a. load at any desired per cent loss, find the ratio of the desired I^2R loss to the I^2R loss upon which the table values are based (corresponding of course to the temperature and the load power-factor). Divide this ratio into the kv.a. to be transmitted. The result will be the table kv.a. value corresponding to the desired I^2R loss.

For example: Assume 400 kv.a. is to be delivered a distance of 14 miles at 6,000 volts, three-phase, and 80 per cent power-factor lagging, at an assumed temperature of 25°C. The table indicates that this condition will be met with an I^2R loss of 10.8 per cent if No. 0 copper or 167,800 circ. mil aluminum conductors are used.

Now assume that the I^2R loss should not exceed 5.4 per cent, in place of 10.8 per cent (upon which the table values are based). $5.4 \div 10.8 = 0.5$ and $400 \div 0.5 = 800$ kv.a. as the table value corresponding to an I^2R loss of 5.4 per cent. The conductors corresponding to 800 kv.a. table value (5.4 per cent I^2R loss) will be seen to be No. 0000 copper or 336,420 circ. mil aluminum.

If conductors corresponding to 15 per cent I^2R loss are desired the same procedure will be followed: $15 \div 10.8 = 1.39$ and $400 \div 1.39 = 287$ kv.a. table value. This table value corresponds to approximately No. 1 copper or 133,220 circ. mil aluminum conductors.

The table kv.a. values have been tabulated for various distances. Should the actual distance be different from the table values and it is desired to obtain kv.a. values corresponding to the losses upon which the table kv.a. values have been calculated, the following procedure may be followed:

For a given I^2R loss in a given conductor (effect of charging current neglected) the kv.a. × feet or the kv.a. × miles is a constant. Thus the table indicates that for 2,000,000 circ. mil cable, 756,000 kv.a. × feet is the constant; that is 756 kv.a. may be transmitted 1,000 ft.; 378 kv.a., 2,000 ft., and so on. If the actual

distance to be transmitted is 1,300 ft. the corresponding kv.a. value will be 756,000 ÷ 1,300 or 581 kv.a. Usually the kv.a. value can readily be approximated for any distance with sufficient accuracy for the purpose for which these quick estimating tables are presented. One way of doing this would be as follows: The kv.a. value corresponding to 2,500 ft. is 302 kv.a. Hence the value corresponding to half this distance (1,250 ft.) is 604 kv.a., which is sufficiently accurate for practical purposes.

REACTANCE LIMITATIONS

The kv.a. value of the tables naturally do not take into account the reactance of the circuit. A check on the value of reactance should always be made when using these tables by referring to the Ratio of Reactance to Resistance tables Nos. XIII to XVI. It will be necessary in some cases of low voltage and single conductors (where the reactance is high) to use lower values of kv.a. or even in some cases to multiple circuits in order to keep the reactance within satisfactory operating limits. This will be considered later by examples on voltage regulation.

HEATING LIMITATIONS

The kv.a. values given in these tables do not take into account the heating and consequently carrying capacity of the conductors. This may be ignored in the case of the longer overhead high-voltage transmission circuits. For very short circuits (especially for the lower voltages and particularly for insulated or concealed conductors) the carrying capacity (safe heating limits) of the conductors must be carefully considered. For circuits of short length the carrying capacity of conductors will frequently determine these sizes and not the economic transmission loss. The carrying capacity of bare copper conductors suspended in air is given in Chapter XVIII and of insulated copper conductors in duct lines are given in tables of Chapter XVI on "Cable Characteristics."

Running diagonally across the quick estimating tables for the lower voltages, is a heavy zig zag line. The point at which this heavy line intersects the horizontal line containing the kv.a. values for a given size of conductor indicates approximately the point at which the carrying capacity of that particular conductor is reached if insulated and installed in a fully loaded four duct line. If the conductor is to be installed in a duct line having more than four ducts its capacity will be still further reduced. The position of this line is based upon the use of lead-covered, paper-insulated, three-conductor, copper cables for sizes up to 700,000 circ. mils and of lead-covered, paper-insulated, single-conductor, copper cables for the larger sizes. In other words, the position of this heavy line is based upon the kv.a. values for carrying capacity given in the table in Chapter "Cable Characteristics" and is placed upon the tables as a warning that the heating limit capacity of the conductors must be considered. To illustrate, suppose 220 volts is to be delivered, over 1,000,000 circ. mil, insulated, single-conductor, copper cables in a fully-loaded four-duct conduit. The quick estimating table indicates that 189 kv.a. can be transmitted over these conductors a distance of 2,000 ft. without overheating the cable. If it is desired to transmit 378 kv.a. a distance of 1,000 ft., the fact that this value occurs to the left of the heavy line, indicates that it is beyond the safe carrying capacity for this size conductor in a four-duct line. Reference to the heating table in Chapter "Cable Characteristics" will show that 297 kv.a. is the maximum capacity of this cable under the conditions stated. In this case, either a larger conductor, or two or more smaller conductors must be used to prevent overheating. This will result in a less loss than those upon which the table kv.a. values are based, and in this case the heating of the cable will probably determine the size to use.

EFFECT OF CHARGING CURRENT IN ABOVE I^2R LOSS VALUES

As stated previously, the per cent I^2R losses in the quick estimating tables are based upon the load current and therefore do not take into account the effect of the charging current which is of a distributed nature and superimposed upon the load current. The effect of the charging current is to increase or decrease the current in the circuit by an amount depending upon the relative values of the lagging and leading quadrature component of the current in the circuit.

For instance assume that the power-factor of the load is unity. In such case there is no quadrature component in the load current. If, however, the circuit is of considerable length, and particularly if the frequency is 60 cycles, there will be an appreciable amount of charging current (quadrature leading component) added vectorially to the load current. The sum of these two currents in quadrature with each other will result in an increase of current in the circuit with a consequent increase in the I^2R loss. Thus the effect of charging current in a circuit delivering a load of 100 per cent power-factor will always be to increase the I^2R loss.

If, however, the power-factor of the load is lagging, there will be a lagging component in the load current. The charging or leading current will be practically in opposition to the lagging component of the load current and will therefore tend to cancel or neutralize the lagging component of the load current. The result will be a reduction of the current in the circuit and consequently in the I^2R loss. But if the circuit is very long, particularly if the frequency is 60 cycles and the load power-factor is near unity (lagging component in load current small) the comparatively large leading component (charging current) will not only neutralize the lagging component of the load current, but will produce a leading power-factor at points along the circuit. If the charging current is sufficiently high it will increase the current, causing an increase in the I^2R loss. Thus the effect of charging current in circuits delivering a lagging load is to decrease the I^2R loss up

to a certain amount and then, if the charging current is sufficiently large, to increase I^2R loss.

The curves in Fig. 13 show this effect for 25- and 60-cycle circuits delivering loads of unity power-factor; also loads of 80 per cent lagging power-factor for circuits up to 500 miles long. It will be seen that for circuits 300 miles long the effect of charging current will be to reduce the I^2R loss by approximately 25 per cent if the load is 80 per cent lagging. If the load power-factor is unity the I^2R loss will be increased approximately 10 per cent for these particular problems if the frequency is 25, and 30 per cent if the frequency is 60 cycles.

taken; that is, the vector sum of load, lowering transformers and phase modifiers (when used) should be taken.

The amount that the charging current will impair the accuracy of the quick-estimating tables depends upon the transmission voltage, length of circuit, frequency, power-factor, amount of power transmitted and size of conductors. Because of so many variables, the tables corresponding to the higher voltages must not be relied upon for accuracy, but must be considered only as a rough check against gross errors in calculation.

The error in applying the quick estimating tables to long lines will be a minimum when the P.F. at the

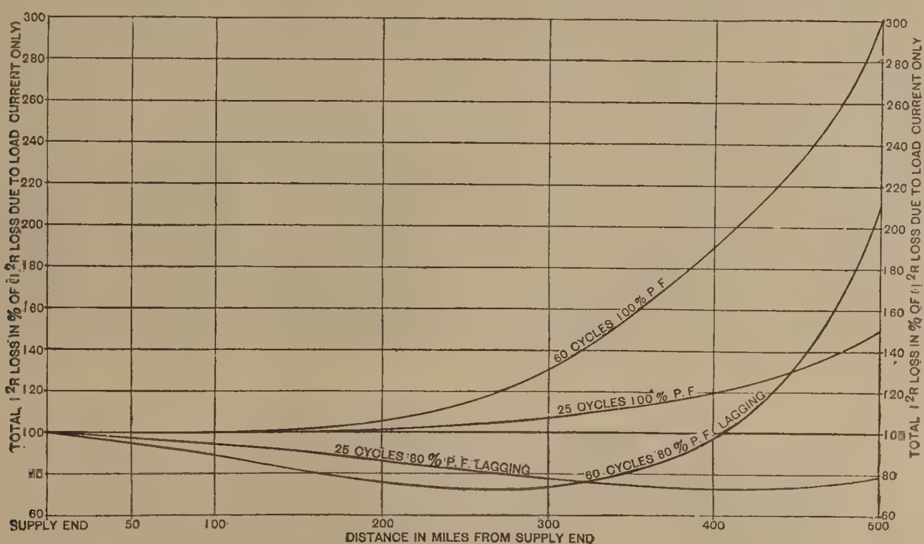


FIG. 13.—Effect of charging current on I^2R transmission loss.

The curves represent (for certain circuits) an approximation of the resultant I^2R loss, compared to what it would have been if there were no charging current present in the circuit. The effect of the charging current superimposed upon the receiver current is either to increase or to decrease the I^2R loss of the circuit depending principally upon the relative amount of the leading and lagging components of the current in the circuit.

The curves in Fig. 13 show that for circuits 500 miles long, in which the entire charging current is furnished from one end of the circuit, the effect of this charging current is to increase the I^2R loss by 200 per cent if the frequency is 60 cycle and the load power-factor 100 per cent. In other words a large part of the current in the circuit for such a long 60-cycle circuit is charging current so that the effect of the load current on the I^2R loss is comparatively small. Of course such a long circuit, unless fed from two or more generating stations located at widely separated points along the transmission line, would not be commercially practical.

In applying the tables, the kv.a. and power-factor at the receiving end of the transmission line should be receiving end is somewhat lagging, the amount depending upon the circuit constants. In such case, starting with the current at the receiving end the superimposed line charging current will cause an increasing P.F. and consequently a falling-off in current value as the middle of the line is approached until unity P.F. is reached and passed, after which the resulting leading P.F. will cause the current to increase as the sending end is approached. Such a distribution of current along the conductors will give an average current value for the entire line nearest to the receiving end current upon which current the quick estimate tables are based. Such a load condition is frequently approached in long lines where phase modifiers are used for voltage control.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

220 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000		15125	7562	5042	3781	3025	2521	1890	1512	1260	1008	756	504	378	302	216	151	143
	1 800 000		13730	6865	4577	3432	2746	2288	1716	1373	1144	915	686	458	343	274	196	137	130
	1 700 000		12821	6410	4274	3205	2564	2137	1602	1282	1068	855	641	427	320	256	183	128	121
	1 600 000		12100	6050	4033	3025	2420	2016	1512	1210	1008	806	605	403	302	242	173	121	114
	1 500 000		11321	5660	3774	2830	2264	1887	1415	1132	943	755	566	377	283	226	162	113	107
	1 400 000		10579	5289	3526	2644	2116	1763	1322	1058	881	705	529	353	264	211	151	106	100
	1 200 000		9047	4523	3015	2262	1809	1507	1131	905	753	603	452	301	226	181	129	90	85
	1 100 000		8345	4172	2782	2086	[illegible]	1391	1043	834	695	556	417	278	209	167	119	83	78
	1 000 000	1 590 000	7562	3781	2521	1890	1512	1260	945	756	630	504	378	252	189	151	108	76	72
	950 000	1 515 000	7224	3612	2408	1806	1445	1204	903	722	602	482	361	241	181	144	103	72	68
	900 000	1 431 000	6817	3408	2272	1704	1363	1136	852	682	568	454	341	227	170	136	98	68	64
	850 000	1 351 500	6410	3205	2136	1602	1282	1068	801	641	534	427	320	214	160	128	91	64	61
	800 000	1 272 000	6050	3025	2017	1512	1210	1008	756	605	504	403	302	202	151	121	86	60	57
	750 000	1 192 500	5678	2839	1893	1420	1135	947	710	568	473	378	284	189	142	113	81	57	54
	700 000	1 113 000	5290	2645	1763	1322	1058	881	661	529	440	353	264	176	132	105	75	53	50
	650 000	1 033 500	4914	2457	1638	1228	983	819	614	491	409	328	246	164	123	98	70	49	45
	600 000	954 000	4523	2262	1507	1131	905	753	565	452	376	302	226	151	113	90	64	45	43
	550 000	874 500	4173	2086	1391	1043	834	695	522	417	347	278	209	139	104	83	59	42	39
	500 000	795 000	3781	1890	1260	945	756	630	472	378	315	252	189	126	94	75	54	38	36
	450 000	715 500	3396	1698	1132	849	679	566	425	340	283	226	170	113	85	68	49	34	32
	400 000	636 000	3034	1517	1011	758	607	505	379	303	252	202	152	101	76	60	43	30	29
	350 000	556 500	2645	1322	882	661	529	441	330	264	220	176	132	88	66	53	38	26	25
	300 000	477 000	2267	1133	755	567	453	378	283	227	189	151	113	75	57	45	32	23	21
	250 000	397 500	1898	949	633	474	379	316	237	190	158	126	95	63	47	38	27	19	18
0000	211 600	336 420	1600	800	533	400	320	266	200	160	133	107	80	53	40	32	23	16	15
000	167 772	266 800	1274	637	425	318	255	212	159	127	106	85	64	42	32	25	18	13	12
00	133 079	211 950	1008	504	336	252	202	168	126	101	84	67	50	34	25	20	14	10	9
0	105 560	167 800	800	400	266	200	160	133	100	80	66	53	40	27	20	16	11	8	8
1	83 694	133 220	632	316	211	158	126	106	79	63	53	42	32	21	16	12	9	6	6
2	66 358	105 530	501	250	167	125	100	83	62	50	41	33	25	17	12	10	7	5	5
3	52 624	83 640	396	198	132	99	79	66	49	40	33	26	20	13	10	8	6	4	4
4	41 738	66 370	316	158	105	79	63	52	39	32	26	21	16	10	8	6	5	3	3
5	33 088	52 630	251	125	84	62	50	42	31	25	21	16	12	8	6	5	4	2	2
6	26 244	41 740	198	99	66	50	40	33	25	20	16	13	10	6	5	4	3	2	2
7	20 822		157	78	52	39	31	26	20	16	13	10	8	5	4	3	2	1	1
8	16 512		125	62	42	31	25	21	15	12	10	8	6	4	3	2	2	1	1

440 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000		60500	30250	20166	15125	12100	10083	7562	6050	5042	4033	3025	2017	1512	1210	864	605	573
	1 800 000		54922	27461	18307	13730	10988	9153	6865	5492	4576	3648	2746	1831	1373	1094	784	549	520
	1 700 000		51285	25642	17095	12821	10257	8547	6410	5128	4273	3419	2564	1710	1282	1026	732	513	485
	1 600 000		48400	24200	16133	12100	9680	8066	6050	4840	4033	3226	2420	1613	1210	968	691	484	458
	1 500 000		45286	22643	15095	11322	9057	7547	5661	4528	3773	3019	2264	1510	1132	906	646	453	429
	1 400 000		42317	21158	14105	10579	8463	7052	5289	4231	3526	2821	2115	1410	1057	846	604	423	400
	1 200 000		36187	18093	12062	9047	7237	6031	4523	3618	3015	2412	1809	1206	904	724	517	362	343
	1 100 000		33379	16687	11126	8344	6676	5563	4172	3337	2782	2225	1668	1113	834	668	477	334	315
	1 000 000	1 590 000	30250	15125	10083	7562	6050	5042	3781	3025	2521	2016	1512	1008	756	605	432	302	287
	950 000	1 515 000	28896	14448	9632	7224	5779	4816	3612	2889	2408	1926	1444	963	722	578	412	289	273
	900 000	1 431 000	27268	13634	9089	6817	5453	4544	3408	2726	2272	1817	1363	909	682	545	389	273	258
	850 000	1 351 500	25642	12821	8547	6410	5128	4273	3205	2564	2136	1709	1282	855	641	513	366	256	243
	800 000	1 272 000	24200	12100	8066	6050	4840	4033	3025	2420	2016	1613	1210	807	605	484	346	242	226
	750 000	1 192 500	22710	11355	7570	5677	4542	3785	2838	2271	1892	1514	1135	757	567	454	324	227	215
	700 000	1 113 000	21158	10579	7053	5289	4231	3527	2644	2115	1763	1410	1057	705	528	423	302	211	[illegible]
	650 000	1 033 500	19655	9827	6552	4913	3931	3276	2456	1965	1638	1310	982	655	491	393	281	196	186
	600 000	954 000	18093	9046	6031	4523	3618	3015	2261	1809	1507	1206	904	603	452	362	258	181	171
	550 000	874 500	16690	8345	5563	4172	3338	2781	2086	1669	1390	1113	834	556	417	334	238	167	158
	500 000	795 000	15125	7562	5042	3781	3025	2521	1890	1512	1260	1008	756	504	378	302	216	151	143
	450 000	715 500	13586	6793	4529	3396	2717	2264	1698	1358	1132	905	679	453	340	272	194	139	129
	400 000	636 000	12138	6069	4046	3034	2427	2023	1517	1213	1012	809	607	405	303	243	173	121	115
	350 000	556 500	10579	5289	3526	2644	2115	1763	1322	1058	881	705	529	353	264	211	151	106	100
	300 000	477 000	9068	4534	3023	2267	1813	1512	1133	906	756	604	453	302	226	181	129	91	86
	250 000	397 500	7592	3796	2531	1898	1518	1265	949	759	632	506	379	253	189	152	108	76	72
0000	211 600	336 420	6400	3200	2133	1600	1280	1067	800	640	533	426	320	213	160	128	91	64	61
000	167 772	266 800	5095	2547	1698	1273	1019	849	636	509	425	339	254	170	127	102	73	51	48
00	133 079	211 950	4033	2016	1344	1008	806	672	504	403	336	268	202	134	101	81	58	40	38
0	105 560	167 800	3200	1600	1066	800	640	533	400	320	266	213	160	107	80	64	46	32	30
1	83 694	133 220	2530	1265	843	632	506	422	316	253	211	169	127	84	63	51	36	25	24
2	66 358	105 530	2006	1003	669	501	401	334	250	200	167	134	100	67	50	40	28	20	19
3	52 624	83 640	1586	793	529	396	317	264	198	158	132	105	79	53	[illegible]	32	22	16	15
4	41 738	66 370	1265	632	423	316	253	212	158	126	106	84	63	42	32	25	18	13	12
5	33 088	52 630	1003	502	334	253	201	167	125	100	83	67	50	33	25	20	14	[illegible]	9
6	26 244	41 740	791	395	264	197	158	132	98	79	66	53	39	26	20	16	11	8	8
7	20 822		629	314	210	157	126	105	78	63	52	41	32	21	16	15	9	6	6
8	16 512		500	250	166	125	100	83	62	50	42	33	25	17	12	10	7	5	5

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

550 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	50 FEET	100 FEET	150 FEET	200 FEET	250 FEET	300 FEET	400 FEET	500 FEET	600 FEET	750 FEET	1000 FEET	1500 FEET	2000 FEET	2500 FEET	3500 FEET	5000 FEET	1 MILE
	2 000 000 1 800 000 1 700 000		94531 85815 80132	47266 42907 40066	31510 28605 26711	23633 21453 20033	18906 17163 16026	15755 14302 13355	11816 10727 10016	9453 8581 8013	7877 7151 6677	6302 5721 5342	4727 4291 4007	3151 2860 2671	2363 2145 2003	1891 1716 1603	1350 1226 1144	945 858 801	896 812 758
	1 600 000 1 500 000 1 400 000		75625 70760 66120	37812 35380 33060	25208 23587 22040	18906 17690 16530	15125 14152 13224	12604 11793 11020	9453 8845 8265	7562 7076 6612	6302 5896 5510	5042 4717 4408	3781 3538 3306	2521 2353 2204	1891 1769 1653	1512 1415 1322	1081 1011 945	756 708 661	716 670 625
	1 200 000 1 100 000 1 000 000	 1 590 000	56542 52155 47265	28271 26077 23632	18847 17385 15755	14135 13038 11816	11308 10431 9453	9423 8692 7877	7067 6519 5908	5654 5215 4727	4711 4346 3938	3769 3477 3151	2827 2608 2363	1885 1738 1576	1413 1304 1182	1131 1043 945	808 745 675	565 522 473	535 492 448
	950 000 900 000 850 000	1 515 000 1 431 000 1 351 500	45149 42606 40066	22574 21303 20033	15050 14202 13355	11287 10652 10016	9030 8521 8013	7525 7101 6677	5643 5326 5008	4515 4260 4007	3762 3550 3338	3010 2840 2671	2257 2130 2003	1505 1420 1336	1129 1065 1002	903 852 801	645 608 572	452 426 401	426 403 380
	800 000 750 000 700 000	1 272 000 1 192 500 1 113 000	37813 35484 33060	18907 17742 16530	12604 11828 11020	9453 8871 8265	7562 7097 6612	6302 5914 5510	4727 4435 4132	3781 3548 3306	3151 2957 2755	2521 2366 2204	1891 1774 1653	1260 1183 1102	945 887 827	756 708 661	540 507 472	378 355 331	358 335 313
	650 000 600 000 550 000	1 033 500 954 000 874 500	30710 28271 26078	15355 14135 13039	10237 9424 8693	7677 7067 6520	6142 5654 5215	5118 4712 4346	3838 3533 3260	3071 2827 2607	2559 2356 2173	2047 1884 1738	1535 1414 1304	1024 942 869	868 707 652	614 565 522	439 404 372	307 283 261	291 268 247
	500 000 450 000 400 000	795 000 715 500 636 000	23633 21228 18965	11816 10614 9482	7878 7076 6322	5908 5307 4741	4726 4246 3793	3939 3538 3161	2954 2653 2370	2363 2123 1896	1969 1769 1580	1575 1415 1264	1182 1061 948	788 708 632	591 531 474	473 425 379	337 303 271	236 212 190	224 201 180
	350 000 300 000 250 000	556 500 477 000 397 500	16530 14168 11863	8265 7084 5932	5510 4723 3954	4132 3542 2966	3306 2823 2372	2755 2361 1977	2066 1771 1483	1653 1416 1186	1377 1180 988	1103 944 791	826 708 593	551 472 395	413 354 297	331 283 237	236 202 170	165 142 119	156 134 112
0000 000 00	211 600 167 772 133 079	336 420 266 800 211 950	10000 7960 6302	5000 3980 3151	3333 2653 2101	2500 1990 1575	2000 1592 1260	1666 1327 1050	1250 995 787	1000 796 630	833 663 525	666 531 420	500 398 315	333 265 210	250 199 158	200 159 126	143 113 90	100 80 63	95 75 60
0 1 2	105 560 83 694 66 358	167 800 133 220 105 530	5000 3954 3134	2500 1977 1567	1666 1318 1045	1250 988 783	1000 791 627	833 659 522	625 494 392	500 395 313	416 329 261	333 264 209	250 198 157	166 132 105	125 99 78	100 79 63	71 56 45	50 40 31	47 38 30
3 4 5	52 624 41 738 33088	83640 66370 52 630	2479 1977 1567	1239 988 783	826 659 522	620 494 392	496 395 313	413 329 261	310 297 196	248 197 156	207 164 130	165 132 104	124 99 78	83 66 52	62 49 39	50 40 31	35 28 22	25 20 16	24 19 15
6 7 8	26244 20822 16512	41740	1239 984 780	619 492 390	413 328 260	310 246 195	247 197 156	206 164 130	155 123 97	123 98 78	103 82 65	82 65 52	61 49 39	41 33 26	31 25 20	25 20 16	18 14 11	12 10 8	12 9 7

1100 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	100 FEET	200 FEET	300 FEET	500 FEET	750 FEET	1000 FEET	2500 FEET	4000 FEET	1 MILE	$1\frac{1}{4}$ MILES	$1\frac{1}{2}$ MILES	2 MILES	$2\frac{1}{2}$ MILES	3 MILES	$3\frac{1}{2}$ MILES	4 MILES	5 MILES
	2 000 000 1 800 000 1 700 000		189062 171631 160265	94531 85815 80132	63021 57210 53422	37812 34326 32053	25208 22884 21368	18906 17163 16026	7562 6865 6410	4726 4291 4006	3580 3250 3035	2865 2600 2428	2388 2166 2023	1790 1625 1517	1432 1300 1214	1194 1083 1012	1023 928 867	895 812 758	716 650 607
	1 600 000 1 500 000 1 400 000		151250 141520 132240	75625 70760 66120	50416 47173 44080	30250 28304 26448	20166 18868 17631	15125 14152 13224	6050 5661 5289	3781 3538 3306	2865 2680 2505	2291 2144 2003	1910 1786 1669	1432 1340 1252	1145 1072 1002	955 893 834	818 766 716	716 670 626	572 536 501
	1 200 000 1 100 000 1 000 000	 1 590 000	113084 104310 94531	56542 52155 47265	37694 34770 31510	22617 20862 18906	15078 13908 12604	11308 10431 9453	4523 4172 3781	2827 2608 2363	2141 1976 1790	1713 1580 1432	1428 1317 1194	1070 988 895	856 790 716	714 658 597	612 565 512	535 494 447	428 395 358
	950 000 900 000 850 000	1 515 000 1 431 000 1 351 500	90298 85211 80132	45149 42605 40066	30099 28404 26711	18059 17042 16026	12040 11361 10684	9030 8521 8013	3612 3408 3205	2257 2130 2003	1710 1613 1518	1368 1291 1214	1140 1076 1012	855 807 759	684 645 607	570 538 506	489 461 434	427 403 379	342 322 303
	800 000 750 000 700 000	1 272 000 1 192 500 1 113 000	75625 70968 66120	37814 35484 33060	25209 23656 22040	15126 14193 13224	10083 9462 8816	7563 7097 6612	3025 2839 2645	1891 1774 1653	1432 1344 1252	1146 1075 1002	955 896 835	716 672 626	573 537 501	477 448 417	409 384 358	358 336 313	286 268 250
	650 000 600 000 550 000	1 033 500 954 000 874 500	61421 56542 52155	30710 28271 26077	20474 18847 17385	12284 11308 10431	8189 7539 6954	6142 5654 5215	2457 2261 2086	1535 1413 1304	1163 1071 988	930 856 790	775 714 658	582 535 494	466 428 395	388 357 329	332 306 282	291 267 247	232 214 197
	500 000 450 000 400 000	795 000 715 500 636 000	47265 42456 37931	23632 21228 18965	15755 14152 12644	9453 8491 7586	6302 5661 5057	4726 4246 3793	1890 1698 1517	1181 1061 948	895 804 718	716 643 575	597 536 479	447 402 359	358 322 287	298 268 239	256 229 205	223 201 179	179 161 143
	350 000 300 000 250 000	556 500 477 000 397 500	33060 28337 23725	16530 14168 11862	11020 9446 7908	6612 5667 4745	4408 3778 3163	3306 2833 2372	1322 1133 949	826 708 593	626 536 449	501 430 359	417 358 300	313 268 224	250 215 179	208 179 150	179 153 128	156 134 112	125 107 89
0000 000 00	211 600 167 772 133 079	336 420 266 800 211 950	20000 15921 12604	10000 7960 6302	6666 5307 4201	4000 3184 2521	2666 2123 1680	2000 1592 1260	800 637 504	500 398 315	378 301 238	303 241 191	252 201 159	189 150 119	152 120 95	126 100 79	109 86 68	94 75 59	76 60 47
0 1 2	105 560 83 694 66 358	167 800 133 200 105 530	10000 7908 6269	5000 3954 3134	3333 2636 2089	2000 1581 1254	1333 1054 835	1000 791 627	400 316 251	250 198 157	190 150 118	151 120 95	126 100 79	95 75 59	75 60 47	63 50 39	54 42 34	47 37 29	37 30 23
3 4 5	52 624 41 738 33 088	83 640 66 370 52 630	4958 3954 3134	2479 1977 1567	1653 1318 1045	991 791 627	661 527 418	496 395 313	198 158 125	124 99 78	94 75 59	75 60 47	62 50 40	47 37 29	37 30 23	31 25 20	26 21 17	23 18 14	18 15 12
6 7 8	26 244 20 822 16 512	41 740	2479 1967 1561	1239 983 780	826 655 520	496 393 312	330 262 208	248 197 156	99 78 62	62 49 39	47 37 30	37 30 24	31 25 20	23 18 15	18 15 12	15 12 10	14 10 8	12 9 7	9 7 6

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

2200 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	100 FEET	200 FEET	300 FEET	500 FEET	750 FEET	1000 FEET	2500 FEET	4000 FEET	1 MILE	1¼ MILES	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES
	2 000 000		756 000	378 000	252 000	151 000	101 000	75 600	30 200	18 900	14 300	11 460	9 550	7 160	5 730	4 770	4 090	3 580	2 860
	1 800 000		686 000	343 000	229 000	137 000	91 500	68 600	27 400	17 100	13 000	10 400	8 670	6 500	5 200	4 330	3 710	3 250	2 600
	1 700 000		641 000	320 000	214 000	128 000	85 500	64 100	25 600	16 000	12 100	9 710	8 100	6 070	4 850	4 050	3 470	3 040	2 430
	1 600 000		605 000	302 000	202 000	121 000	80 700	60 500	24 200	15 100	11 400	9 170	7 640	5 730	4 580	3 820	3 270	2 860	2 290
	1 500 000		566 000	283 000	189 000	113 000	75 500	56 600	22 600	14 100	10 700	8 580	7 150	5 360	4 290	3 570	3 060	2 680	2 140
	1 400 000		529 000	264 000	176 000	106 000	70 500	52 900	21 100	13 200	10 000	8 010	6 680	5 010	4 010	3 340	2 860	2 500	2 000
	1 200 000		452 000	226 000	151 000	90 500	60 300	45 200	18 100	11 300	8 560	6 850	5 710	4 280	3 430	2 850	2 450	2 140	1 710
	1 100 000		417 000	208 000	139 000	83 400	55 600	41 700	16 700	10 400	7 900	6 320	5 270	3 950	3 160	2 630	2 260	1 970	1 580
	1 000 000	1 590 000	378 000	189 000	126 000	75 600	50 400	37 800	15 100	9 450	7 160	5 730	4 770	3 580	2 860	2 390	2 040	1 790	1 430
	950 000	1 515 000	361 000	180 000	120 000	72 200	48 100	36 100	14 400	9 030	6 840	5 470	4 560	3 420	2 740	2 280	1 950	1 710	1 370
	900 000	1 431 000	341 000	170 000	114 000	68 100	45 400	34 100	13 600	8 520	6 450	5 160	4 300	3 230	2 580	2 150	1 840	1 610	1 290
	850 000	1 351 500	320 000	160 000	107 000	64 100	42 700	32 000	12 800	8 010	6 070	4 860	4 050	3 030	2 430	2 020	1 730	1 520	1 210
	800 000	1 272 000	302 000	151 000	101 000	60 500	40 300	30 200	12 100	7 560	5 730	4 580	3 820	2 860	2 290	1 910	1 640	1 430	1 146
	750 000	1 192 500	284 000	142 000	94 600	56 800	37 800	28 400	11 300	7 100	5 370	4 300	3 580	2 700	2 150	1 790	1 540	1 340	1 070
	700 000	1 113 000	264 000	132 000	88 100	52 900	35 200	26 400	10 600	6 610	5 010	4 010	3 340	2 500	2 000	1 670	1 430	1 250	1 000
	650 000	1 033 500	246 000	123 000	81 900	49 100	32 700	24 500	9 800	6 140	4 650	3 720	3 100	2 330	1 861	1 550	1 330	1 160	931
	600 000	954 000	226 000	113 000	75 400	45 200	30 100	22 600	9 050	5 650	4 280	3 430	2 850	2 140	1 710	1 430	1 220	1 070	857
	550 000	874 500	208 000	104 000	69 500	41 700	27 800	20 800	8 350	5 210	3 950	3 160	2 630	1 970	1 580	1 310	1 130	987	790
	500 000	795 000	189 000	94 500	63 000	37 800	25 200	18 900	7 560	4 730	3 580	2 860	2 380	1 790	1 430	1 190	1 020	895	716
	450 000	715 500	170 000	84 900	56 600	33 900	22 600	17 000	6 800	4 240	3 220	2 570	2 140	1 610	1 290	1 070	920	804	643
	400 000	636 000	152 000	75 800	50 600	30 300	20 200	15 200	6 070	3 790	2 870	2 300	1 910	1 440	1 150	958	824	718	575
	350 000	556 500	132 000	66 100	44 100	26 400	17 600	13 200	5 290	3 310	2 500	2 000	1 670	1 250	1 000	835	716	626	501
	300 000	477 000	113 000	56 700	37 800	22 700	15 100	11 300	4 530	2 830	2 150	1 720	1 430	1 073	860	715	613	536	429
	250 000	397 500	94 900	47 400	31 600	19 000	12 600	9 500	3 800	2 370	1 800	1 440	1 200	900	720	600	513	450	359
0000	211 600	336 420	80 000	40 000	26 700	16 000	10 700	8 000	3 200	2 000	1 510	1 210	1 010	757	606	505	433	378	303
000	167 772	266 800	63 700	31 800	21 200	12 700	8 490	6 370	2 550	1 590	1 200	965	804	603	482	402	345	301	241
00	133 079	211 950	50 400	25 200	16 800	10 100	6 720	5 040	2 000	1 260	955	760	636	477	382	318	273	238	191
0	105 560	167 800	40 000	20 000	13 300	8 000	5 330	4 000	1 600	1 000	757	606	505	380	303	252	217	189	151
1	83 694	133 220	31 600	15 800	10 500	6 330	4 220	3 160	1 260	790	600	480	400	300	239	200	171	150	120
2	66 358	105 530	25 100	12 500	8 360	5 010	3 340	2 510	1 000	630	475	380	317	237	190	158	136	118	95
3	52 624	83 640	19 800	9 900	6 610	3 970	2 640	1 980	790	500	375	300	250	188	150	125	107	94	75
4	41 738	66 370	15 800	7 910	5 270	3 160	2 110	1 580	630	395	300	240	200	150	120	100	86	75	60
5	33 088	52 630	12 500	6 270	4 180	2 510	1 670	1 250	500	313	237	190	159	118	95	79	68	59	47
6	26 244	41 740	9 900	4 960	3 310	1 980	1 320	990	400	250	188	150	125	94	75	63	54	47	37
7	20 822		7 900	3 930	2 620	1 570	1 050	790	310	197	149	119	99	74	59	49	42	37	30
8	16 512		6 250	3 120	2 080	1 250	830	620	250	156	118	95	79	59	47	39	34	30	24

4000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650 000	1 033 000	15400	10 250	7700	6150	5120	4400	3850	3080	2560	2200	1920	1710	1540	1400	1280	1180	1100
	600 000	954 000	14200	9460	7100	5670	4750	4050	3550	2840	2370	2030	1775	1580	1420	1290	1180	1090	1020
	550 000	874 500	13100	8750	6550	5250	4370	3750	3280	2620	2180	1870	1640	1460	1310	1190	1090	1010	940
	500 000	795 000	11900	7950	5950	4750	3960	3400	2980	2380	1980	1700	1490	1320	1190	1080	990	915	850
	450 000	715 500	10700	7120	5350	4270	3560	3060	2670	2140	1780	1530	1330	1190	1070	970	890	822	763
	400 000	636 000	9490	6330	4750	3800	3165	2713	2373	1900	1582	1357	1186	1055	949	863	791	736	678
	350 000	556 500	8270	5510	4 130	3307	2756	2362	2067	1653	1378	1181	1033	919	827	752	689	636	590
	300 000	477 000	7080	4 720	3 540	2832	2359	2023	1769	1416	1179	1011	884	786	708	644	589	545	506
	250 000	397 500	5920	3 950	2960	2370	1975	1693	1481	1185	987	846	740	658	593	539	493	456	423
0000	211 600	336 420	5000	3 330	2 500	2000	1666	1428	1250	1000	833	714	625	555	500	454	416	385	357
000	167 772	266 800	3980	2 650	1990	1592	1326	1137	995	796	663	568	497	442	398	362	331	306	284
00	133 079	211 950	3 140	2 090	1570	1255	1046	896	783	627	523	448	391	349	313	285	261	241	224
0	105 560	167 800	2 500	1 670	1250	1000	833	713	625	500	416	357	312	277	250	227	208	192	178
1	83 694	133 220	1970	1 320	987	790	658	563	493	395	329	282	247	219	197	179	164	152	140
2	66 358	105 530	1570	1 045	783	627	522	448	392	313	261	224	196	174	157	142	130	120	112
3	52 624	83 640	1 240	826	620	496	413	354	310	248	207	177	155	138	124	113	103	95	88
4	41 738	66 370	990	661	495	396	330	283	247	198	167	141	123	110	99	90	82	76	70
5	33 088	52 630	786	524	393	314	262	225	196	157	131	112	98	87	78	71	65	60	56

4400 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650 000	1 033 000	18600	12400	9300	7450	6200	5300	4650	3720	3100	2660	2330	2070	1860	1690	1550	1430	1330
	600 000	954 000	17100	11400	8550	6850	5700	4880	4270	3420	2850	2440	2140	1900	1710	1550	1430	1320	1220
	550 000	874 500	15900	10600	7950	6370	5300	4550	3980	3180	2650	2270	1990	1770	1590	1450	1330	1230	1140
	500 000	795 000	14300	9530	7150	5720	4770	4080	3570	2870	2380	2050	1780	1590	1430	1300	1190	1100	1020
	450 000	715 500	12900	8600	6450	5150	4300	3690	3230	2580	2150	1840	1620	1430	1290	1180	1080	995	920
	400 000	636 000	11500	7650	5750	4600	3830	3290	2880	2300	1920	1640	1440	1280	1150	1050	960	887	825
	350 000	556 500	10000	6670	5000	4000	3330	2860	2500	2000	1670	1430	1250	1110	1000	910	832	770	715
	300 000	477 000	8590	5720	4290	3440	2860	2450	2150	1720	1430	1230	1070	950	858	780	715	660	613
	250 000	397 500	7170	4780	3585	2870	2390	2050	1800	1430	1200	1030	900	800	717	653	600	552	513
0000	211 600	336 420	6050	4030	3025	2420	2020	1730	1510	1210	1010	865	755	673	605	550	505	467	433
000	167 772	266 800	4820	3220	2410	1930	1610	1380	1210	965	805	688	603	535	482	438	402	371	345
00	133 079	211 950	3790	2530	1895	1520	1260	1080	950	758	632	543	475	422	379	345	317	292	271
0	105 560	167 800	3030	2020	1515	1220	1010	867	758	607	506	433	379	337	303	276	253	233	217
1	83 694	133 220	2390	1590	1195	955	795	683	598	478	398	341	299	266	239	217	199	183	171
2	66 358	105 530	1900	1270	950	760	633	542	475	380	317	271	237	211	190	173	158	146	136
3	52 624	83 640	1500	1000	750	600	500	428	375	300	250	214	188	167	150	136	125	116	107
4	41 738	66 370	1200	800	600	480	400	342	300	240	200	172	150	133	120	109	100	92	86
5	33 088	52 630	950	633	475	380	318	272	237	190	158	136	119	106	95	87	80	78	68

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

6000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650000	1033000	34600	23100	17300	13800	11500	9900	8650	6930	5780	4950	4320	3850	3460	3150	2890	2670	2470
	600000	954000	31800	21200	15900	12700	10600	9100	7950	6370	5300	4550	3980	3540	3180	2890	2650	2450	2270
	550000	874500	29500	19700	14700	11800	9850	8430	7370	5900	4920	4220	3690	3280	2950	2680	2460	2270	2110
	500000	795000	26600	17700	13300	10600	8860	7600	6670	5320	4450	3800	3330	2960	2660	2420	2220	2050	1900
	450000	715500	23900	16000	11900	9550	8000	6880	5900	4770	4000	3440	2950	2660	2390	2170	2000	1840	1720
	400000	636000	21300	14200	10700	8540	7120	6100	5340	4270	3561	3050	2670	2370	2130	1940	1780	1640	1530
	350000	556500	18600	12400	9300	7440	6200	5310	4650	3720	3100	2660	2320	2070	1860	1690	1550	1430	1330
	300000	477000	15900	10600	7960	6370	5310	4550	3980	3190	2650	2270	1990	1770	1590	1450	1330	1220	1130
	250000	397500	13300	8890	6670	5330	4440	3810	3330	2670	2220	1900	1670	1480	1330	1210	1110	1020	950
0000	211600	336420	11200	7500	5620	4500	3750	3210	2810	2250	1870	1610	1410	1250	1120	1020	937	866	800
000	167772	266800	8950	5970	4480	3580	2980	2560	2240	1791	1490	1280	1120	995	895	814	746	689	640
00	133079	211950	7060	4710	3530	2820	2350	2020	1760	1410	1180	1010	882	784	706	642	588	543	500
0	105560	167800	5620	3750	2810	2250	1870	1610	1410	1120	937	803	703	625	562	515	468	433	400
1	83694	133220	4440	2960	2220	1780	1480	1270	1110	890	741	634	555	494	444	404	370	342	317
2	66358	105530	3530	2350	1760	1410	1170	1010	882	706	588	504	441	392	353	321	294	271	250
3	52624	83640	2790	1860	1390	1110	930	797	697	558	465	398	348	310	279	253	232	215	200
4	41738	66370	2230	1490	1110	891	743	637	556	446	371	318	278	247	223	202	185	171	160
5	33088	52630	1770	1180	884	708	590	505	442	354	295	252	221	196	177	161	146	136	126

6600 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	1 MILE	1½ MILES	2 MILES	2½ MILES	3 MILES	3½ MILES	4 MILES	5 MILES	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES
	650000	1033000	41900	28000	20900	16800	14000	12000	10500	8400	7000	6000	5250	4670	4190	3830	3500	3230	3000
	600000	954000	38500	25700	19300	15400	12800	11000	9630	7700	6400	5500	4810	4270	3850	3500	3210	2960	2750
	550000	874500	35700	23800	17800	14300	11900	10000	8930	7140	5950	5100	4460	3960	3570	3250	2980	2750	2550
	500000	795000	32300	21500	16100	12900	10800	9250	8075	6460	5400	4620	4030	3600	3230	2940	2690	2480	2310
	450000	715500	29100	19400	14500	11600	9700	8820	7270	5820	4850	4150	3640	3230	2910	2640	2420	2240	2080
	400000	636000	25900	17300	12900	10300	8650	7400	6470	5180	4320	3700	3240	2880	2590	2360	2160	1990	1850
	350000	556500	22600	15000	11300	9040	7520	6450	5650	4520	3770	3220	2820	2510	2260	2050	1880	1740	1610
	300000	477000	19300	12900	9650	7720	6440	6520	4820	3860	3220	2760	2420	2150	1930	1760	1610	1480	1380
	250000	397500	16200	10800	8100	6480	5400	4620	4050	3240	2700	2310	2020	1800	1620	1470	1350	1240	1160
0000	211600	336420	13600	9050	6800	5440	4530	3890	3400	2720	2260	1940	1700	1510	1360	1230	1130	1040	970
000	167772	266800	10800	7200	5400	4320	3600	3080	2700	2160	1800	1540	1350	1200	1080	980	900	830	770
00	133079	211950	8550	5700	4270	3420	2850	2440	2140	1710	1420	1220	1070	950	855	778	713	657	610
0	105560	167800	6800	4520	3400	2720	2260	1940	1700	1360	1130	970	850	755	680	617	565	522	486
1	83694	133220	5380	3590	2690	2150	1790	1530	1340	1070	895	767	672	597	538	490	448	413	385
2	66358	105530	4270	2850	2130	1710	1420	1220	1070	854	710	610	533	477	427	390	356	329	306
3	52624	83640	3380	2250	1690	1350	1130	965	845	676	565	483	422	376	338	307	282	260	241
4	41738	66370	2710	1800	1350	1080	900	775	677	542	450	388	339	300	271	246	226	209	193
5	33088	52630	2140	1420	1070	860	712	612	535	428	356	306	268	238	214	195	178	165	151

10 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	16000	13800	12100	10700	9620	8750	8020	7400	6870	6420	6000	5350	4820	4380	4020	3700	3440
	600000	954000	14800	12700	11100	9820	8850	8050	7350	6800	6320	5900	5530	4920	4420	4020	3680	3410	3160
	550000	874500	13700	11700	10200	9100	8200	7450	6820	6300	5850	5450	5120	4550	4100	3720	3410	3150	2920
	500000	795000	12300	10600	9250	8250	7400	6720	6150	5700	5280	4920	4620	4100	3700	3360	3090	2850	2640
	450000	715500	11100	9550	8450	7420	6680	5080	5560	5130	4770	4450	4170	3700	3340	3040	2780	2570	2390
	400000	636000	9890	8480	7420	6594	5930	5390	4940	4560	4240	3950	3710	3300	2970	2700	2470	2280	2120
	350000	556500	8610	7380	6460	5742	5170	4700	4310	3970	3690	3440	3230	2870	2580	2350	2150	1990	1840
	300000	477000	7370	6320	5530	4910	4420	4020	3690	3400	3160	2950	2760	2460	2210	2010	1840	1700	1580
	250000	397500	6170	5290	4630	4110	3700	3370	3090	2850	2640	2470	2310	2060	1850	1680	1540	1420	1320
0000	211600	336420	5210	4460	3910	3470	3120	2840	2600	2400	2230	2080	1950	1740	1560	1420	1300	1200	1110
000	167772	266800	4140	3550	3110	2760	2490	2260	2070	1910	1780	1660	1550	1380	1240	1130	1040	957	890
00	133079	211950	3270	2800	2450	2180	1960	1780	1630	1510	1400	1310	1220	1090	980	891	817	754	700
0	105560	167800	2600	2230	1950	1740	1560	1420	1300	1200	1110	1040	976	868	781	710	651	601	558
1	83694	133200	2060	1760	1540	1370	1230	1120	1030	949	882	823	771	686	617	561	514	474	441
2	66358	105530	1633	1400	1220	1090	980	891	816	754	700	653	612	544	490	445	408	377	350
3	52624	83640	1290	1110	969	861	775	705	646	596	554	517	484	431	387	352	323	298	277
4	41738	66370	1030	884	774	688	619	563	516	476	442	413	387	344	309	281	258	238	221
5	33088	52630	819	702	614	546	491	447	409	378	351	327	307	273	245	223	204	189	175

11 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	19400	16600	14500	12900	11600	10600	9700	8920	8300	7750	7250	6450	5800	5270	4850	4450	4150
	600000	954000	17800	15300	13400	11900	10700	9750	8900	8230	7650	7150	6680	5950	5350	4870	4450	4120	3820
	550000	874500	16500	14200	12400	11100	9920	9000	8250	7620	7080	6600	6200	5500	4960	4500	4120	3810	3540
	500000	795000	14900	12800	11200	10000	8970	8170	7450	6900	6400	5980	5600	5000	4480	4080	3720	3450	3200
	450000	715500	13500	11500	10100	8950	8070	7350	6750	6200	5770	5380	5050	4470	4030	3670	3370	3100	2880
	400000	636000	12000	10300	9000	8000	7200	6550	6000	5550	5150	4800	4500	4000	3600	3270	3000	2780	2570
	350000	556500	10500	8950	7820	6960	6270	5680	5250	4830	4470	4180	3910	3480	3130	2840	2620	2410	2230
	300000	477000	8920	7650	6700	5980	5350	4870	4460	4120	3830	3560	3350	2990	2670	2430	2230	2060	1910
	250000	397500	7470	6400	5600	4980	4480	4070	3730	3440	3200	2990	2800	2490	2240	2030	1870	1720	1600
0000	211600	336420	6300	5400	4730	4200	3780	3440	3150	2910	2700	2530	2360	2100	1890	1720	1570	1450	1350
000	167772	266800	5020	4300	3760	3340	3010	2740	2510	2310	2150	2010	1880	1670	1500	1370	1250	1150	1070
00	133079	211950	3960	3390	2960	2640	2370	2150	1980	1820	1700	1580	1480	1320	1180	1070	990	910	850
0	105560	167800	3150	2700	2370	2100	1890	1720	1570	1450	1350	1260	1180	1050	945	860	787	725	675
1	83694	133220	2490	2140	1870	1670	1490	1360	1240	1150	1070	1000	935	835	747	680	622	575	535
2	66358	105530	1980	1700	1480	1320	1180	1080	990	910	845	790	740	660	592	540	495	455	422
3	52624	83640	1570	1340	1170	1040	940	850	785	720	670	627	585	520	469	425	392	360	335
4	41738	66370	1250	1070	940	836	750	685	625	578	537	503	471	418	376	342	312	289	268
5	33088	52630	990	850	740	660	590	540	495	457	424	395	371	330	296	270	247	228	212

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

12 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	23100	19800	17300	15400	13900	12600	11600	10700	9900	9250	8650	7700	6950	6300	5800	5350	4950
	600000	954000	21200	18200	15900	14200	12700	11600	10600	9800	9100	8500	7950	7100	6350	5800	5300	4900	4550
	550000	874500	19700	16900	14800	13200	11800	10800	9850	9100	8450	7900	7400	6600	5900	5400	4920	4550	4220
	500000	795000	17800	15300	13300	11900	10700	9700	8900	8200	7600	7100	6650	5900	5350	4850	4450	4100	3800
	450000	715500	16000	13700	12000	10600	9600	8600	8000	7380	6850	6400	6000	5300	4800	4300	4000	3690	3420
	400000	636000	14200	12200	10700	9490	8540	7770	7120	6570	6100	5700	5340	4750	4270	3880	3560	3290	3050
	350000	556500	12400	10600	9300	8270	7440	6760	6200	5720	5300	4960	4650	4130	3720	3380	3100	2860	2660
	300000	477000	10600	9100	7960	7080	6370	5790	5310	4900	4550	4250	3980	3540	3190	2890	2650	2450	2270
	250000	397500	8900	7620	6670	5920	5330	4850	4440	4100	3810	3550	3330	2960	2670	2420	2220	2050	1900
0000	211600	336420	7500	6430	5620	5000	4500	4090	3750	3460	3210	3000	2810	2500	2250	2040	1870	1730	1610
000	167772	266800	5970	5120	4480	3980	3580	3250	2990	2750	2560	2390	2240	1990	1791	1630	1490	1380	1280
00	133079	211950	4710	4033	3530	3140	2820	2560	2350	2170	2010	1880	1760	1570	1410	1280	1180	1090	1010
0	105560	167800	3750	3210	2810	2500	2250	2050	1870	1730	1610	1500	1410	1250	1120	1020	930	865	803
1	83694	133220	2960	2540	2220	1970	1780	1610	1480	1370	1270	1180	1110	990	890	810	740	683	635
2	66358	105530	2350	2010	1760	1570	1410	1280	1170	1090	1010	940	880	780	700	640	590	543	504
3	52624	83640	1860	1590	1390	1240	1110	1010	930	860	790	740	700	620	560	510	460	430	400
4	41738	66370	1490	1270	1110	990	890	810	740	680	640	590	560	490	440	400	370	343	318
5	33088	52630	1180	1010	884	780	710	640	590	540	500	472	440	390	350	320	295	272	252

13 200 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	27900	24000	20900	18600	16700	15200	14000	12900	12000	11200	10400	9300	8370	7600	7000	6450	6000
	600000	954000	25700	22000	19300	17100	15400	14000	12800	11800	11000	10300	9650	8550	7700	7000	6400	5920	5500
	550000	874500	23900	20400	17900	15900	14300	13000	11900	11000	10200	9550	8950	7950	7150	6500	5950	5500	5100
	500000	795000	21500	18500	16100	14300	12900	11700	10700	9920	9220	8600	8050	7150	6450	5850	5350	4960	4610
	450000	715500	19300	16600	14500	12900	11600	10600	9700	8930	8280	7750	7250	6450	5800	5300	4850	4460	4140
	400000	636000	17300	14800	12900	11500	10300	9420	8650	8000	7400	6900	6450	5750	5170	4710	4320	4000	3700
	350000	556500	15100	12900	11300	10000	9020	8200	7520	6950	6450	6020	5650	5000	4510	4100	3760	3470	3220
	300000	477000	12900	11000	9650	8570	7720	7020	6430	5930	5520	5150	4820	4280	3860	3510	3210	2960	2760
	250000	397500	10800	9250	8080	7180	6450	5870	5380	4960	4620	4300	4040	3600	3220	2930	2700	2480	2310
0000	211600	336420	9100	7800	6850	6070	5450	4970	4550	4200	3900	3640	3420	3030	2720	2480	2270	2100	1950
000	167772	266800	7220	6200	5420	4820	4330	3940	3620	3330	3100	2890	2710	2410	2160	1970	1810	1660	1550
00	133079	211950	5700	4900	4280	3800	3420	3110	2850	2630	2450	2280	2140	1900	1710	1550	1420	1310	1220
0	105560	167800	4550	3900	3410	3030	2730	2480	2270	2100	1950	1820	1700	1510	1360	1240	1130	1050	975
1	83694	133220	3590	3070	2690	2390	2150	1960	1800	1660	1540	1430	1340	1200	1070	980	900	830	770
2	66358	105530	2850	2440	2140	1900	1710	1560	1430	1320	1220	1140	1070	950	850	780	710	660	610
3	52624	83640	2250	1930	1680	1500	1350	1220	1120	1030	960	900	840	750	670	610	560	510	480
4	41738	66370	1800	1550	1360	1200	1080	985	900	830	770	720	680	600	540	490	450	420	390
5	33088	52630	1420	1220	1070	950	850	778	710	660	610	570	530	470	430	390	360	330	300

15 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650000	1033000	36000	31000	27000	24000	21600	19800	18000	16600	15400	14400	13500	12000	10800	9900	9000	8300	7700
	600000	954000	33200	28500	24900	22200	19900	18200	16600	15300	14200	13300	12400	11100	9950	9100	8300	7650	7100
	550000	874500	30600	26300	23000	20500	18400	16700	15300	14100	13100	12300	11500	10200	9200	8350	7650	7050	6550
	500000	795000	27800	23900	20800	18600	16700	15200	13900	12800	11900	11100	10400	9300	8350	7600	6950	6400	5950
	450000	715500	25000	21400	18700	16700	15000	13600	12500	11500	10700	10000	9350	8350	7500	6800	6250	5750	5350
	400000	636000	22200	19100	16700	14800	13300	12100	11100	10200	9540	8900	8340	7420	6670	6070	5560	5130	4770
	350000	556500	19400	16600	14500	12900	11600	10600	9690	8940	8300	7750	7260	6460	5810	5280	4840	4470	4150
	300000	477000	16600	14200	12400	9260	9960	9050	8290	7660	7100	6640	6220	5530	5000	4520	4150	3830	3550
	250000	397500	13900	11900	10400	7810	8330	7570	6940	6410	5950	5560	5210	4630	4160	3790	3470	3200	2980
0000	211600	336420	11700	10000	8790	6220	7030	6390	5860	5410	5020	4680	4390	3910	3510	3200	2930	2700	2510
000	167772	266800	9330	8000	7000	4900	5600	5090	4660	4300	4000	3730	3500	3110	2800	2540	2330	2150	2000
00	133079	211950	7350	6300	5510	3910	4410	4010	3670	3390	3150	2940	2760	2450	2210	2000	1840	1700	1570
0	105560	167800	5860	5000	4390	3090	3510	3190	2930	2700	2510	2340	2200	1950	1760	1600	1460	1350	1250
1	83694	133220	4630	3970	3470	2450	2780	2520	2310	2140	1980	1850	1740	1540	1390	1260	1160	1070	990
2	66358	105530	3670	3150	2760	1940	2210	2000	1840	1690	1570	1470	1380	1220	1100	1000	920	850	780
3	52624	83640	2910	2490	2180	1550	1740	1590	1450	1340	1240	1160	1090	970	870	790	730	670	620
4	41738	66370	2320	1990	1740	1230	1390	1270	1160	1070	990	930	870	774	690	630	580	530	490
5	33088	52630	1840	1580	1380	970	1110	1000	920	850	790	730	690	614	430	500	460	420	390

16 500 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	6 MILES	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES
	650 000	1 033 000	45400	38900	34000	30300	27200	24700	22700	21000	19500	18200	17000	15100	13600	12300	11300	10500	9750
	600 000	954 000	40200	34500	30200	26800	24100	21900	20100	18600	17200	16100	15100	13400	12000	10900	10000	9300	8600
	550 000	874 500	37200	31900	27900	24800	22300	20300	18600	17200	15900	14800	13900	12400	11100	10100	9300	8600	7950
	500 000	795 000	33700	28900	25300	22500	20200	18300	16800	15500	14400	13500	12600	11200	10100	9150	8400	7750	7200
	450 000	715 500	30400	26000	22800	20300	18200	16600	15200	14000	13000	12100	11400	10100	9100	8300	7600	7000	6500
	400 000	636 000	27000	23100	20200	18000	16200	14700	13500	12400	11600	10800	10100	9000	8100	7350	6750	6200	5800
	350 000	556500	23700	20300	17700	15800	14200	12900	11800	10900	10200	9480	8850	7900	7100	6450	5900	5450	5100
	300 000	477000	20200	17200	15100	13400	12100	11000	10100	9300	8650	8060	7550	6700	6050	5500	5050	4650	4320
	250 000	397500	16800	14400	12600	11200	10100	9200	8450	7780	7220	6720	6300	5600	5050	4600	4220	3890	3610
0000	211600	336420	14200	12200	11700	9500	8520	7770	7100	6560	6080	5700	5850	4750	4260	3880	3550	3280	3040
000	167772	266800	11300	9700	8500	7550	6780	6170	5670	5220	4860	4530	4250	3770	3390	3080	2830	2610	2430
00	133079	211950	8920	7650	6700	5950	5370	4870	4460	4120	3830	3580	3350	2970	2670	2430	2230	2060	1910
0	105560	167800	7100	6100	5320	4720	4260	3860	3540	3270	3040	2840	2660	2360	2130	1930	1770	1630	1520
1	83694	133220	5620	4820	4220	3750	3370	3070	2810	2590	2410	2250	2110	1870	1680	1530	1400	1290	1200
2	66358	105530	4450	3820	3340	2970	2670	2430	2230	2060	1910	1780	1670	1480	1330	1210	1110	1030	950
3	52624	83640	3540	3030	2650	2360	2120	1930	1760	1630	1510	1410	1320	1180	1060	960	880	810	750
4	41738	66370	2820	2420	2120	1880	1690	1530	1410	1300	1210	1130	1060	940	840	760	700	650	600
5	33088	52630	2220	1900	1670	1480	1330	1210	1120	1020	950	890	830	740	670	600	560	510	480

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

20 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES
	650 000	1 033 000	55000	47200	42700	38500	34900	32000	29600	27500	25700	23600	21300	19200	17400	16000	14800	13400	12800
	600 000	954 000	50500	44200	39400	35400	32200	29500	27200	25300	23600	22100	19700	17700	16100	14700	13600	12700	11800
	550 000	874 500	46800	41000	36500	32800	29800	27300	25200	23400	21800	20500	18200	16400	14900	13600	12600	11700	10900
	500 000	795 000	42500	37000	33000	29700	27000	24700	22800	21200	19800	18500	16500	14800	13500	12300	11400	10600	9900
	450 000	715 500	38200	33400	29600	26600	24300	22200	20500	19000	17800	16700	14800	13300	12100	11100	10200	9500	8900
	400 000	636 000	33900	29600	26400	23700	21600	19800	18200	16900	15800	14800	13200	11800	10800	9890	9130	8480	7910
	350 000	556 500	29500	25800	23000	20700	18800	17200	15900	14700	13800	12900	11500	10300	9400	8610	7950	7380	6890
	300 000	477 000	25300	22100	19700	17700	16100	14700	13600	12600	11800	11000	9830	8850	8050	7370	6810	6320	5900
	250 000	397 500	21100	18500	16400	14800	13400	12300	11400	10600	9880	9260	8230	7410	6730	6170	5700	5290	4940
0000	211 600	336 420	17800	15600	13900	12500	11300	10400	9610	8930	8330	7810	6940	6250	5680	5210	4810	4460	4170
000	167 772	266 800	14200	12400	11000	9950	9040	8230	7650	7110	6630	6220	5530	4970	4520	4150	3830	3550	3310
00	133 079	211 950	11200	9800	8710	7840	7130	6530	6030	5600	5230	4900	4360	3920	3560	3270	3010	2800	2610
0	105 560	167 800	8930	7810	6940	6250	5680	5210	4810	4460	4170	3910	3470	3120	2840	2600	2400	2230	2080
1	83 694	133 220	7050	6170	5490	4940	4490	4110	3810	3530	3290	3090	2740	2470	2240	2060	1900	1760	1640
2	66 358	105 530	5600	4900	4360	3920	3560	3270	3020	2800	2610	2450	2180	1960	1780	1630	1510	1400	1310
3	52 624	83 640	4430	3870	3440	3100	2820	2590	2380	2210	2070	1940	1720	1550	1410	1290	1190	1110	1030
4	41 738	66 370	3540	3100	2750	2480	2250	2060	1900	1770	1650	1550	1380	1240	1120	1030	950	884	820
5	33 088	52 630	2810	2460	2180	1960	1790	1640	1510	1400	1310	1230	1090	980	890	820	750	700	650

22 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	7 MILES	8 MILES	9 MILES	10 MILES	11 MILES	12 MILES	13 MILES	14 MILES	15 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES
	650 000	1 033 000	66500	58200	51800	46600	42200	38800	35800	33300	31000	29100	25900	23300	21100	19400	17900	16600	15500
	600 000	954 000	61200	53500	47600	42800	38900	35600	32900	30600	27500	26700	23800	21400	19400	17800	16400	15300	13700
	550 000	874 500	56800	49600	44200	39700	36100	33100	30500	28400	26600	24800	22100	19800	18000	16500	15200	14200	13200
	500 000	795 000	51300	44800	40000	35900	32600	29900	27600	25700	23900	22400	20000	17900	16300	14900	13800	12800	11900
	450 000	715 500	46000	40200	35800	32200	29300	26900	24800	23000	21500	20100	17900	16100	14600	13400	12400	11500	10700
	400 000	636 000	41200	36000	32000	28800	26200	24000	22200	20600	19200	18000	16000	14400	13100	12000	11100	10300	9600
	350 000	556 500	35800	31400	27900	25100	22800	20900	19300	17900	16700	15700	13900	12550	11400	10400	9650	8950	8350
	300 000	477 000	30600	26700	23800	21400	19400	17800	16500	15300	14200	13300	11900	10700	9700	8900	8250	7650	7100
	250 000	397 500	25600	22400	19900	17900	16300	14900	13800	12800	12000	11200	9950	8950	8150	7450	6900	6400	6000
0000	211 600	336 420	21500	18900	16800	15100	13700	12600	11600	10800	10100	9450	8400	7550	6850	6300	5800	5400	5050
000	167 772	266 800	17300	15100	13400	12100	11000	10100	9300	8650	8080	7550	6700	6050	5500	5050	4650	4320	4040
00	133 079	211 950	13600	11800	10600	9500	8650	7920	7300	6780	6330	5900	5300	4750	4320	3960	3650	3390	3160
0	105 560	167 800	10800	9450	8380	7550	6860	6300	5820	5400	5030	4720	4190	3770	3430	3150	2910	2700	2510
1	83 694	133 220	8520	7480	6650	5970	5420	4980	4600	4270	3980	3740	3320	2980	2710	2490	2300	2130	1980
2	66 358	105 530	6780	5950	5280	4750	4320	3960	3660	3400	3180	2970	2640	2370	2160	1980	1830	1700	1590
3	52 624	83 640	5360	4680	4170	3750	3410	3130	2890	2680	2500	2340	2080	1870	1700	1560	1440	1340	1250
4	41 738	66 370	4300	3770	3340	3010	2740	2510	2320	2150	2010	1880	1670	1500	1370	1250	1160	1070	1000
5	33 088	52 630	3390	2970	2640	2370	2160	1980	1820	1690	1580	1480	1320	1180	1080	990	910	840	790

30 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	12 MILES	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES
	650 000	1 033 000	72200	62000	54200	48200	43200	39400	36100	33300	30900	28900	27100	24100	21600	19700	18000	16600	15400
	600 000	954 000	66200	56800	49700	44200	39800	36200	33200	30500	28400	26500	24800	22100	19900	18100	16600	15200	14200
	550 000	874 500	61500	52800	46200	41000	36900	33500	30800	28400	26400	24700	23100	20500	18400	16700	15400	14200	13200
	500 000	795 000	55600	47800	41800	37100	33400	30400	27900	25700	23900	22300	20900	18500	16700	15200	13900	12800	11900
	450 000	715 500	50000	42800	37500	33400	30000	27300	25100	23100	21500	20000	18700	16700	15000	13600	12500	11500	10700
	400 000	636 000	44500	38100	33400	29700	26700	24300	22200	20500	19100	17800	16700	14800	13300	12100	11100	10200	9540
	350 000	556 500	38700	33200	29100	25800	23200	21100	19400	17900	16600	15500	14500	12900	11600	10600	9690	8940	8300
	300 000	477 000	33200	28400	24900	22100	19900	18100	16600	15300	14200	13200	12400	11000	9950	9050	8290	7660	7100
	250 000	397 500	27800	23800	20800	18500	16700	15100	13900	12800	11900	11100	10400	9260	8330	7570	6940	6400	5950
0000	211 600	336 420	23400	20100	17600	15600	14100	12800	11700	10800	10000	9370	8790	7810	7030	6390	5860	5410	5020
000	167 772	266 800	18600	16000	14000	12400	11200	10200	9330	8610	8000	7460	7000	6220	5600	5090	4660	4300	4000
00	133 079	211 950	14700	12600	11030	9800	8820	8020	7350	6790	6300	5880	5510	4900	4410	4010	3670	3390	3150
0	105 560	167 800	11700	10000	8800	7810	7030	6390	5860	5400	5020	4690	4390	3910	3510	3190	2930	2700	2510
1	83 694	133 220	9260	7940	6940	6170	5550	5050	4630	4270	3970	3700	3470	3090	2780	2520	2310	2140	1980
2	66 358	105 530	7350	6300	5510	4900	4410	4010	3670	3390	3150	2940	2760	2450	2210	2000	1840	1690	1570
3	52 624	83 640	5810	4980	4360	3880	3490	3170	2910	2680	2490	2330	2180	1940	1740	1580	1450	1340	1240
4	41 738	66 370	4640	3980	3480	3100	2790	2530	2320	2140	1990	1860	1740	1550	1390	1270	1160	1070	990
5	33 088	52 630	3681	3160	2760	2450	2210	2010	1840	1700	1580	1470	1380	1230	1100	1000	920	850	790

33 000 VOLTS DELIVERED

B & S NO.	COPPER	ALUMINUM	12 MILES	14 MILES	16 MILES	18 MILES	20 MILES	22 MILES	24 MILES	26 MILES	28 MILES	30 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES
	650 000	1 033 000	87200	74700	65300	58200	52200	47600	43700	40200	37400	34800	32650	29100	26100	23800	21800	20100	18700
	600 000	954 000	80200	68800	60200	53600	48200	43800	40200	37100	34400	32100	30100	26800	24100	21900	20100	18500	17200
	550 000	874 500	75500	64800	56700	50400	45300	41200	37700	34800	32400	30300	28300	25200	22600	20600	18800	17400	16200
	500 000	795 000	67300	57800	50600	45000	40400	36800	33700	31100	28900	27000	25300	22500	20200	18400	16800	15500	14400
	450 000	715 500	60400	51800	45300	40200	36300	33000	30200	27900	25900	24100	22600	20100	18100	16500	15100	13900	12900
	400 000	636 000	54000	46300	40600	36000	32400	29500	27000	25000	23200	21600	20300	18000	16200	14700	13500	12500	11600
	350 000	556 500	47000	40300	35300	31400	28200	25700	23500	21700	20200	18800	17600	15700	14100	12800	11700	10800	10100
	300 000	477 000	40200	34500	30200	26900	24100	21900	20100	18600	17300	16100	15100	13400	12000	10900	10000	9300	8650
	250 000	397 500	33700	28800	25200	22400	20200	18300	16800	15500	14400	13400	12600	11200	10100	9150	8400	7750	7200
0000	211 600	336 420	28300	24300	21200	18900	17000	15400	14200	13100	12200	11400	10600	9450	8500	7700	7100	6550	6100
000	167 772	266 800	22600	19300	16900	15000	13500	12300	11300	10500	9680	9050	8450	7500	6750	6150	5650	5200	4840
00	133 079	211 950	17800	15200	13300	11800	10700	9700	8900	8220	7620	7120	6650	5900	5350	4850	4450	4110	3810
0	105 560	167 800	14200	12200	10600	9460	8520	7750	7100	6550	6080	5680	5300	4730	4260	3870	3550	3270	3040
1	83 694	133 220	11200	9600	8400	7480	6720	6120	5600	5180	4820	4500	4200	3740	3360	3060	2800	2590	2410
2	66 358	105 530	8900	7620	6670	5920	5330	4850	4450	4100	3810	3560	3340	2960	2670	2430	2230	2050	1910
3	52 624	83 640	7050	6050	5300	4700	4230	3850	3520	3250	3020	2820	2650	2350	2110	1920	1760	1620	1510
4	41 738	66 370	5650	4850	4230	3760	3390	3080	2820	2610	2420	2260	2110	1880	1690	1540	1410	1300	1210
5	33 088	52 630	4430	3800	3330	2960	2670	2420	2220	2050	1900	1770	1660	1480	1330	1210	1110	1020	950

* The heating limitations may, for the shorter distances, particularly if insulated or concealed conductors are employed, necessitate the use of larger conductors, resulting in a correspondingly less transmission loss. In the case of insulated or concealed conductors, should the kv.a. values fall near or to the left of the heavy line, consult the table on page 163 for insulated or the table on page 186 for bare conductors. The reactance for the larger conductors may be excessive, particularly for 60-cycle service, producing excessive voltage drop. This may be obviated by installing two or more parallel circuits or using three-conductor cables. For single-phase circuits the kv.a. will be one-half the table values.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

40 000 VOLTS DELIVERED

B & S No.	Copper Area in Circular Mils	Aluminum Area in Circular Mils	14 Miles	16 Miles	18 Miles	20 Miles	22 Miles	24 Miles	26 Miles	28 Miles	30 Miles	32 Miles	36 Miles	40 Miles	44 Miles	48 Miles	52 Miles	56 Miles	60 Miles
	650000	1033000	110000	96000	85300	76800	70000	64200	59000	55000	51300	48000	42600	38400	35000	32100	29500	27500	25600
	600000	954000	101000	88700	78800	70800	64500	59000	54500	50700	47300	44300	39400	35400	32200	29500	27200	25300	23600
	550000	874500	93800	82000	73000	65500	59700	54700	50500	46800	43700	41000	36500	32700	29800	27300	25200	23400	21800
	500000	795000	84600	74000	66000	59200	54000	49400	45600	42300	39500	37000	33000	29600	27000	24700	22800	21100	19700
	450000	715500	76300	66700	59200	53500	48500	44500	41000	38100	35600	33300	29600	26700	24200	22200	20500	19000	17800
	400000	636000	67800	59300	52700	47500	43100	39500	36500	33900	31600	29700	26400	23700	21600	19800	18200	16900	15800
	350000	556500	59000	51700	45900	41300	37600	34400	31800	29500	27500	25800	23000	20700	18800	17200	15900	14700	13800
	300000	477000	50600	44200	39300	35400	32200	29500	27200	25300	23600	22100	19700	17700	16100	14700	13600	12600	11800
	250000	397500	42300	37000	32900	29600	26900	24700	22800	21100	19700	18500	16400	14800	13500	12300	11400	10600	9880
0000	211600	336420	35700	31200	27800	25000	22700	20800	19200	17800	16700	15600	13900	12500	11400	10400	9610	8930	8330
000	167772	266800	28400	24800	22100	19900	18100	16600	15300	14200	13200	12400	11000	9950	9040	8230	7650	7110	6630
00	133079	211950	22400	19600	17400	15700	14200	13100	12100	11200	10400	9800	8710	7840	7130	6530	6030	5600	5230
0	105560	167800	17800	15600	13900	12500	11300	10400	9620	8930	8330	7810	6940	6250	5680	5210	4810	4460	4170
1	83694	133220	14100	12300	10900	9880	8980	8230	7590	7050	6580	6170	5490	4940	4490	4110	3800	3530	3290
2	66358	105530	11200	9800	8710	7840	7130	6540	6030	5600	5230	4900	4360	3920	3560	3270	3020	2800	2610
3	52624	83640	8860	7750	6880	6200	5640	5170	4770	4430	4130	3870	3440	3100	2820	2580	2380	2210	2070
4	41738	66370	7070	6190	5500	4950	4500	4130	3810	3540	3300	3090	2750	2480	2250	2060	1910	1770	1650
5	33088	52630	5610	4910	4370	3930	3570	3280	3020	2810	2620	2460	2180	1960	1790	1640	1510	1400	1310

44 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	14 Miles	16 Miles	18 Miles	20 Miles	22 Miles	24 Miles	26 Miles	28 Miles	30 Miles	32 Miles	36 Miles	40 Miles	44 Miles	48 Miles	52 Miles	56 Miles	60 Miles
	650000	1033000	133000	116000	103000	93000	84500	77500	71500	66500	62000	58000	51500	46500	42200	38700	35700	33200	31000
	600000	954000	122000	107000	95000	85500	77800	71500	66000	61200	57200	53500	47500	42700	38900	35700	33000	30600	28600
	550000	874500	113000	99000	88000	79200	72000	66000	61000	56500	52800	49500	44000	39600	36000	33000	30500	28200	26400
	500000	795000	102000	89700	79700	71800	65300	59800	55200	51300	47800	44800	39800	35900	32600	29800	27600	25600	23900
	450000	715500	92200	80700	71600	64500	58700	53800	49700	46200	43000	40300	35800	32200	29300	26900	24800	23100	21500
	400000	636000	82200	72000	64000	57700	52300	48000	44200	41200	38400	36000	32000	28800	26100	24000	22100	20600	19200
	350000	556500	71800	62800	55800	50200	45600	41800	38700	35800	33500	31400	27900	25100	22800	20900	19300	17900	16700
	300000	477000	61300	53600	47700	42800	39000	35700	33000	30600	28600	26800	23800	21400	19500	17850	16500	15300	14300
	250000	397500	51200	44800	39800	35800	32600	29900	27600	25600	23900	22400	19900	17900	16300	14900	13800	12800	11900
0000	211600	336420	43200	37900	33700	30300	27500	25200	23300	21600	20200	18950	16800	15100	13700	12600	11600	10800	10100
000	167772	266800	34400	30100	26800	24100	21900	20100	18500	17200	16000	15050	13400	12000	10900	10000	9250	8600	8000
00	133079	211950	27100	23700	21100	19000	17300	15800	14600	13500	12600	11850	10500	9500	8650	7900	7300	6750	6300
0	105560	167800	21700	18900	16800	15100	13800	12600	11700	10800	10100	9450	8400	7550	6900	6300	5850	5400	5050
1	83694	133200	17100	14900	13300	11900	10800	9970	9200	8550	7970	7450	6650	5900	5400	4980	4600	4270	3980
2	66358	105530	13500	11800	10500	9470	8600	7880	7280	6770	6320	5900	5250	4730	4300	3940	3640	3380	3160
3	52624	83640	10700	9400	8350	7520	6830	6250	5780	5360	5000	4700	4170	3760	3410	3120	2890	2680	2500
4	41738	66370	8600	7500	6680	6000	5470	5000	4620	4300	4000	3750	3340	3000	2730	2500	2310	2150	2000
5	33088	52630	6780	5930	5270	4750	4320	3960	3660	3400	3170	2960	2630	2370	2160	1980	1830	1700	1580

50 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	20 Miles	24 Miles	28 Miles	32 Miles	36 Miles	40 Miles	44 Miles	48 Miles	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles
	650000	1033000	120000	100000	86000	75000	66800	60000	54800	50200	46200	43000	40000	37500	33400	30000	27400	25100	23100
	600000	954000	111000	92500	79200	69200	61500	55500	50300	46200	42500	39600	37000	34600	30700	27700	25100	23100	21200
	550000	874500	103000	85500	73500	64200	57000	51300	46600	42800	39500	36700	34300	32100	28500	25600	23300	21400	19700
	500000	795000	92800	77200	66200	58000	51500	46400	42200	38700	35600	33100	30900	29000	25700	23200	21100	19300	17800
	450000	715500	83800	69500	59800	52200	46500	41800	38000	35000	32200	29900	27900	26100	23200	20900	19000	17500	16100
	400000	636000	74200	61800	53000	46300	41200	37100	33700	30900	28500	26500	24700	23200	20600	18500	16900	15400	14200
	350000	556500	64600	53800	46100	40400	35900	32300	29300	26900	24800	23100	21500	20200	17900	16100	14700	13400	12400
	300000	477000	55300	46100	39500	34600	30700	27600	25100	23000	21300	19700	18400	17300	15400	13800	12600	11500	10600
	250000	397500	46300	38600	33100	28900	25700	23100	21000	19300	17800	16500	15400	14500	12900	11600	10500	9640	8900
0000	211600	336420	39100	32500	27900	24400	21700	19500	17800	16200	15000	13900	13000	12200	10800	9760	8880	8140	7510
000	167772	266800	31100	25900	22200	19400	17300	15500	14100	13000	11900	11100	10400	9720	8640	7770	7070	6480	5980
00	133079	211950	24500	20400	17500	15300	13600	12200	11100	10200	9430	8750	8170	7660	6810	6130	5570	5100	4710
0	105560	167800	19500	16300	13900	12200	10800	9760	8880	8140	7510	6970	6510	6100	5420	4880	4440	4070	3760
1	83694	133220	15400	12900	11020	9640	8570	7710	7010	6430	5930	5510	5140	4822	4290	3860	3510	3210	2970
2	66358	105530	12200	10200	8751	7660	6810	6130	5570	5100	4710	4370	4080	3833	3400	3060	2780	2550	2350
3	52624	83640	9690	8070	6920	6060	5380	4840	4400	4040	3730	3460	3230	3030	2690	2420	2200	2020	1860
4	41738	66370	7740	6450	5530	4840	4300	3870	3520	3220	2980	2760	2580	2420	2150	1930	1760	1610	1490
5	33088	52630	6140	5120	4390	3840	3410	3070	2790	2560	2360	2190	2050	1920	1710	1530	1400	1280	1180

60 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	20 Miles	24 Miles	28 Miles	32 Miles	36 Miles	40 Miles	44 Miles	48 Miles	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles
	650000	1033000	173000	144000	124000	108000	96000	86600	78800	72200	66500	61800	57700	54000	48000	43300	39400	36100	33200
	600000	954000	159000	133000	114000	99500	88500	74600	72500	66500	61300	57000	53200	49700	44200	39800	36200	33200	30700
	550000	874500	148000	123000	106000	92500	82200	74000	67300	61800	57000	52800	49400	46200	41100	37000	33600	30900	28500
	500000	795000	133000	111000	95000	83500	74000	66600	60500	55500	51200	47500	44400	41700	37000	33300	30200	27700	25600
	450000	715500	120000	100000	85700	75200	66700	60000	54700	50200	46300	42800	40000	37600	33300	30000	27300	25100	23100
	400000	636000	107000	89000	76300	66700	59300	53400	48500	44500	41100	38100	35600	33400	29700	26700	24200	22200	20500
	350000	556500	93000	77500	66400	58100	51700	46500	42300	38700	35800	33200	31000	29100	25800	23200	21100	19400	17900
	300000	477000	79600	66300	56900	49800	44200	39800	36200	33100	30600	28400	26500	24900	22100	19900	18100	16600	15300
	250000	397500	66700	55500	47600	41700	37000	33300	30300	27800	25600	23800	22200	20800	18500	16700	15100	13900	12800
0000	211600	336420	56200	46900	40200	35100	31200	28100	25500	23400	21600	20100	18700	17600	15600	14100	12800	11700	10800
000	167772	266800	44800	37300	32000	28000	24800	22400	20300	18600	17200	16000	14900	14000	12400	11200	10200	9330	8610
00	133079	211950	35300	29400	25200	22000	19600	17600	16000	14700	13600	12600	11700	11000	9800	8820	8020	7350	6790
0	105560	167800	28100	23400	20100	17600	15600	14000	12800	11700	10800	10000	9370	8790	7810	7030	6390	5860	5410
1	83694	133220	22200	18500	15800	13900	12300	11100	10100	9260	8550	7930	7410	6940	6170	5550	5050	4630	4270
2	66358	105530	17600	14700	12600	11000	9800	8820	8020	7350	6790	6300	5880	5510	4900	4410	4010	3670	3390
3	52624	83640	13900	11600	9970	8720	7750	6980	6340	5810	5370	4980	4650	4360	3880	3490	3170	2910	2680
4	41738	66370	11100	9290	7960	6970	6190	5570	5070	4640	4290	3980	3710	3480	3100	2790	2530	2320	2140
5																			

*The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with the table on page 17, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See text.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

66 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	20 MILES	24 MILES	28 MILES	32 MILES	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES
	650 000	1 033 000	210000	174000	150000	131000	116000	105000	95300	87500	80800	75000	69800	65500	58000	52500	47600	43700	40400
	600 000	954 000	193000	161000	138000	120000	107000	96200	87500	80200	74200	68800	64300	60000	53500	48100	43700	40100	37100
	550 000	874 500	178000	148000	127000	111000	99000	89200	81000	74200	68700	63800	59500	55500	49500	44600	40500	37100	34300
	500 000	795 000	161000	134000	115000	101000	89500	80500	73300	67000	62000	57600	53700	50500	44700	40200	36600	33500	31000
	450 000	715 500	145000	121000	104000	91000	80700	72700	66000	60500	56000	51800	48500	45500	40300	36300	33000	30200	28000
	400 000	636 000	130000	108000	92700	81000	72000	65000	59000	54000	50000	46300	43300	40500	36000	32500	29500	27000	25000
	350 000	556 500	113000	94000	80500	70500	62500	56500	51500	47200	43500	40500	37700	35200	31200	28200	25700	23600	21700
	300 000	477 000	96000	80000	68700	60000	53500	48000	43700	40000	37000	34300	32000	30000	26700	24000	21800	20000	18500
	250 000	397 500	80500	67200	57600	50500	44700	40300	36700	33600	31000	28800	26900	25200	22300	20100	18300	16800	15500
0000	211 600	336 420	68000	56700	48700	42500	37700	34000	31000	28300	26100	24300	22700	21200	18800	17000	15500	14100	13000
000	167 772	266 800	54000	45000	38600	33900	30100	27100	24600	22500	20800	19300	18100	16900	15000	13500	12300	11200	10400
00	133 079	211 950	42500	35500	30400	26600	23700	21300	19300	17700	16300	15200	14200	13300	11800	10600	9650	8850	8150
0	105 560	167 800	34000	28400	24300	21300	18900	17000	15500	14200	13100	12200	11300	10600	9450	8500	7750	7100	6550
1	83 694	133 220	27000	22500	19300	16800	15000	13500	12200	11200	10400	9600	8900	8400	7500	6750	6100	5600	5200
2	66 358	105 530	21300	17800	15200	13300	11800	10600	9700	8900	8200	7600	7100	6650	5900	5300	4850	4450	4100
3	52 624	83 640	16800	14000	12000	10500	9300	8400	7600	7000	6400	6000	5600	5250	4670	4200	3820	3500	3240
4	41 738	66 370	13500	11200	9600	8400	7500	6700	6100	5600	5200	4800	4500	4210	3750	3375	3070	2810	2600

70 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	130000	118000	107000	98000	90600	84000	78600	73500	65500	59000	53500	49000	45300	42000	39300	36700	32700
	600 000	954 000	120000	108000	98500	90500	83500	77500	72300	67700	60300	54000	49200	45200	41700	37700	36100	33800	30100
	550 000	874 500	112000	100000	91200	83500	77500	71700	67000	62600	55800	50000	45600	41700	37700	35800	33200	31300	27900
	500 000	795 000	101000	90500	82500	75500	69800	64800	60500	56700	50500	45200	41200	37700	34900	32400	30200	28300	25200
	450 000	715 500	90800	81600	74200	68000	62800	58500	54500	51000	45500	41800	37100	34000	31400	29200	27200	25500	22700
	400 000	636 000	80800	72700	66100	60600	55900	51900	48400	45400	40400	36300	33000	30300	28000	25900	24200	22700	20200
	350 000	556 500	70300	63300	57500	52700	48700	45200	42200	39500	35100	31600	28800	26400	24300	22600	21100	19700	17600
	300 000	477 000	60200	54200	49200	45100	41700	38700	36100	33900	30100	27100	24600	22600	20800	19300	18000	16900	15000
	250 000	397 500	50400	45300	41200	37800	34900	32400	30200	28300	25200	22700	20600	18900	17400	16200	15100	14200	12600
0000	211 600	336 420	42500	38300	34800	31900	29400	27300	25500	23900	21200	19100	17400	15900	14700	13600	12600	11900	10600
000	167 772	266 800	33800	30400	27700	25400	23400	21700	20300	19000	16900	15200	13800	12700	11700	10900	10100	9520	8460
00	133 079	211 950	26700	24000	21800	20000	18400	17100	16000	15000	13300	12000	10900	10000	9240	8580	8000	7500	6670
0	105 560	167 800	21200	19100	17400	15900	14700	13600	12700	12000	10600	9570	8700	7970	7360	6830	6380	6000	5310
1	83 694	133 220	16800	15100	13700	12600	11600	10800	10100	9450	8400	7560	6870	6300	5820	5400	5040	4720	4200
2	66 358	105 530	13300	12000	10900	10000	9240	8580	8000	7500	6670	6000	5460	5000	4620	4290	4000	3750	3330
		83 640	10500	9500	8630	7920	7300	6780	6330	5900	5270	4750	4320	3960	3670	3390	3160	2970	2640

80 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	171000	154000	140000	128000	118000	110000	102000	96000	85500	77000	70000	64000	59000	55000	51000	48000	42700
	600 000	954 000	157000	142000	128000	118000	109000	101000	94500	88500	78500	71000	64000	59000	54500	50500	47700	44200	39200
	550 000	874 500	146000	131000	119000	110000	101000	93600	87600	82000	72800	65500	59500	55000	50500	46800	43800	41000	36400
	500 000	795 000	132000	119000	108000	99000	91500	85000	79000	74200	66000	59500	54000	47500	45700	42500	39500	37100	33000
	450 000	715 500	118000	107000	97000	88800	82000	76200	71000	66700	59200	53500	48500	44400	41000	38100	35500	33300	29600
	400 000	636 000	105000	94900	86300	79100	73000	67800	63300	59300	52700	47400	43100	39500	36500	33900	31600	29600	26300
	350 000	556 500	91800	82600	75100	68900	63600	59000	55100	51600	45900	41300	37500	34400	31800	29500	27500	20800	22900
	300 000	477 000	78600	70800	64300	59000	54400	50500	47200	44200	39300	35400	32100	29500	27200	25300	23600	22100	19600
	250 000	397 500	65800	59200	53800	49400	45600	42300	39500	37000	32900	29600	26900	24700	22800	21100	19700	18500	16400
0000	211 600	336 420	55500	50000	45400	41700	38400	35700	33300	31200	27800	25000	22700	20800	19200	17800	16700	15600	13900
000	167 772	266 800	44200	39800	36200	33100	30600	28400	26500	24800	22100	19900	18100	16600	15300	14200	13200	12400	11000
00	133 079	211 950	34800	31300	28500	26100	24100	22400	20900	19600	17400	15600	14200	13100	12100	11200	10400	9800	8700
0	105 560	167 800	27800	25000	22700	20800	19200	17800	16700	15600	13900	12500	11300	10400	9610	8930	8330	7810	6940
1	83 694	133 220	21900	19700	17900	16400	15200	14100	13100	12300	10900	9880	8980	8230	7600	7050	6580	6170	5490
		105 530	17400	15700	14200	13100	12100	11200	10400	9800	8710	7840	7130	6530	6030	5600	5230	4900	4360

88 000 VOLTS DELIVERED

B & S NO.	COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	36 MILES	40 MILES	44 MILES	48 MILES	52 MILES	56 MILES	60 MILES	64 MILES	72 MILES	80 MILES	88 MILES	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES
	650 000	1 033 000	207000	186000	169000	155000	143000	133000	124000	116000	103000	93000	84500	77500	71500	66500	62000	58000	51500
	600 000	954 000	191000	171000	156000	143000	132000	122000	114000	107000	95500	85500	78000	71500	66000	61000	57000	53500	47700
	550 000	874 500	177000	159000	144000	132000	122000	113000	106000	99500	88200	79500	72000	66000	61000	56500	53000	49700	44100
	500 000	795 000	159000	143000	131000	120000	111000	102000	96000	90000	80000	71500	65500	60000	55500	51000	48000	45000	40000
	450 000	715 500	143000	129000	117000	107000	99000	92000	86000	80600	71500	64500	58500	53500	49500	46000	43000	40300	35700
	400 000	636 000	128000	115000	105000	96000	88700	82500	76800	72000	64000	57500	52500	48000	44300	41200	38400	36000	32000
	350 000	556 500	111000	100000	91200	83500	77200	71600	67000	62700	55800	50000	45600	41750	38600	35800	33500	31300	27900
	300 000	477 000	95000	85500	78000	71500	66000	61200	57200	53600	47700	42700	39000	35700	33000	30600	28600	26800	23800
	250 000	397 500	79500	71500	65000	59800	55000	51000	47800	44800	39800	35700	32500	29900	27500	25500	23900	22400	19900
0000	211 600	336 420	67200	60500	55000	50500	46200	43200	40300	37800	33600	30200	27500	25200	23200	21600	20100	18900	16800
000	167 772	266 800	53500	48200	43800	40200	37000	34400	32200	30200	26800	24100	21900	20100	18500	17200	16100	15100	13400
00	133 079	211 950	42300	38000	34600	31700	29300	27200	25400	23800	21200	19100	17300	15800	14600	13600	12700	11900	10600
0	105 560	167 800	33700	30300	27600	25300	23300	21700	20200	19000	16800	15100	13800	12600	11600	10800	10100	9500	8400
1	83 694	133 220	26500	23900	21700	19900	18300	17000	15900	14900	13200	11900	10850	9900	9100	8500	7900	7400	6600
		105 530	21100	19000	17200	15800	14600	13500	12600	11900	10500	9500	8600	7900	7300	6700	6300	5900	5200

* The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with the table on page 17, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See text.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

100 000 VOLTS DELIVERED

B & S No.	Copper Area in Circular Mils	Aluminum Area in Circular Mils	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles
	650 000	1 033 000	185000	172000	160000	150000	133000	120000	109000	100000	92500	86000	80000	75000	66500	60000	54500	50000	46200
	600 000	954 000	170000	158000	148000	138000	123000	110000	101000	92500	85500	79000	74000	69000	61500	55000	50500	46200	42700
	550 000	874 500	158000	147000	137000	128000	114000	103000	93500	85500	79000	73500	68500	64000	57000	51500	46700	42700	39500
	500 000	795 000	143000	132000	124000	116000	103000	93000	84500	77500	71500	66000	62000	58000	51500	46500	42200	38700	35700
	450 000	715 500	128000	119000	111000	104000	93000	83500	76000	69500	64200	59500	55500	52000	46500	41700	38000	34700	32100
	400 000	636 000	114000	106000	98900	92700	82400	74200	67400	61800	57000	53000	49400	46300	41200	37100	33700	30900	28500
	350 000	556 500	99400	92300	86100	80700	71800	64600	58700	53800	49700	46100	43000	40300	35900	32300	29300	26900	24800
	300 000	477 000	85100	79000	73700	69100	61400	55300	50300	46100	42500	39500	36800	34500	30700	27600	25100	23000	21200
	250 000	397 500	71200	66100	61700	57800	51400	46300	42100	38600	35600	33000	30800	28900	25700	23100	21000	19300	17800
0000	211 600	336 420	60100	55800	52100	48800	43400	39000	35500	32500	30000	27900	26000	24400	21700	19500	17700	16200	15000
000	167 772	266 800	47800	44400	41400	38800	34500	31100	28200	25900	23900	22200	20700	19400	17200	15500	14100	12900	11900
00	133 079	211 950	37700	35000	32700	30600	27200	24500	22300	20400	18800	17500	16300	15300	13600	12200	11100	10200	9400
0	105 560	167 800	30000	27900	26000	24400	21700	19500	17700	16300	15000	13900	13000	12200	10800	9800	8900	8100	7500
		133 220	23700	22000	20600	19300	17100	15400	14000	12900	11900	11000	10300	9600	8600	7700	7000	6400	5900
		105530	18800	17500	16300	15300	13600	12200	11100	10200	9400	8700	8200	7600	6800	6100	5600	5100	4700

110 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	52 Miles	56 Miles	60 Miles	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles
	650 000	1 033 000	224000	208000	194000	182000	162000	146000	133000	121000	112000	104000	97000	91000	81000	73000	66500	60500	56000
	600 000	954 000	206000	191000	178000	167000	148000	134000	122000	111000	103000	95500	89000	83500	74000	67000	61000	55500	51500
	550 000	874 500	191000	177000	165000	155000	138000	124000	113000	103000	95500	88500	82500	77500	69000	62000	56500	54500	47700
	500 000	795 000	173000	160000	150000	140000	125000	112000	102000	93500	86000	80000	75000	70000	62500	56000	51000	46700	43000
	450 000	715 500	155000	144000	134000	126000	112000	101000	91600	84000	77600	72000	67000	63000	56000	50500	45800	42000	38800
	400 000	636 000	138000	128000	119000	112000	99700	89700	81600	74800	69000	64100	59800	56100	49800	44900	40800	37400	34500
	350 000	556 500	120000	111000	104000	97700	86800	78100	71000	65100	60100	55800	52100	48800	43400	39100	35500	32500	30000
	300 000	477 000	103000	95600	89200	83600	74300	66900	60800	55700	51500	47800	44600	41800	37210	33400	30400	27900	25700
	250 000	397 500	86100	80000	74700	70000	62200	56000	50600	46600	43100	40000	37300	35000	31100	28000	25300	23300	21500
0000	211 600	336 420	72700	67500	63000	59100	52500	47200	42900	39400	36300	33700	31500	29500	26200	23600	21500	19700	18200
000	167772	266 800	57800	53700	50100	47000	41800	37600	34200	31300	28900	26800	25100	23500	20900	18800	17100	15600	14400
00	133079	211 950	45600	42300	39500	37000	32900	29600	26900	24700	22800	21100	19800	18500	16400	14800	13500	12300	11400
		167 800	36300	33700	31500	29500	26200	23600	21400	19700	18100	16900	15700	14700	13129	11800	10700	9800	9100
		133 220	28700	26600	24900	23300	20700	18600	16900	15500	14300	13300	12400	11670	10300	9300	8500	7800	7200

120 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	216000	192000	173000	157000	144000	133000	123000	115000	108000	96000	86500	78500	72000	66500	61500	57500	54000
	600 000	954 000	199000	177000	160000	145000	133000	123000	114000	106000	100000	88500	80000	72500	66500	61500	57000	53000	50000
	550 000	874 500	184000	164000	148000	134000	123000	113000	105000	98500	92500	82000	74000	67000	61500	56500	52500	49200	46200
	500 000	795 000	167000	148000	133000	121000	111000	102000	95000	89000	83500	74000	66500	60500	55500	51000	47500	44500	41700
	450 000	715 500	150000	133000	120000	109000	100000	92500	86000	80000	75000	66500	60000	54500	50000	46200	43000	40000	37500
	400 000	636 000	133000	119000	107000	97100	89000	82100	76300	71200	66700	59300	53400	48500	44500	41100	38100	35600	33300
	350 000	556 500	116000	103000	93000	84500	77500	71500	66400	62000	58100	51600	46500	42200	38700	35800	33200	31000	29100
	300 000	477 000	99000	88500	79600	72400	66400	61200	56900	53100	49800	44200	39800	36200	33100	30600	28400	26500	24800
	250000	397 500	83000	74100	66700	60600	55500	51200	47600	44400	41600	37000	33300	30300	27700	25600	23800	22200	20800
0000	211 600	336 420	70300	62500	56200	51100	46800	43200	40100	37500	35100	31200	28100	25500	23400	21600	20100	18700	17500
000	167772	266 800	56000	49700	44800	40700	37300	34400	32000	29800	28000	24800	22300	20300	18600	17200	16000	14900	14000
		211 950	44100	39200	35300	32100	29400	27100	25200	23500	22000	19600	17600	16000	14700	13500	12600	11700	11000
		167 800	35100	31200	28100	25600	23400	21600	20100	18700	17500	15600	14000	12700	11700	10800	10000	9300	8800

132 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	262000	233000	210000	191000	175000	161000	150000	140000	131000	116000	105000	95500	87500	80500	75000	70000	65500
	600 000	954 000	242000	215000	193000	176000	161000	148000	138000	129000	121000	107000	96500	88000	80500	74000	69000	64500	60500
	550 000	874 500	223000	198000	178000	162000	149000	137000	128000	109000	112000	99000	89000	81000	74500	68500	64000	54500	56000
	500 000	795 000	202000	179000	161000	147000	134000	124000	115000	107000	101000	89500	80500	73500	67000	62000	57500	53500	55050
	450 000	715 500	182000	161000	145000	132000	121000	112000	104000	96800	90800	80500	72500	66000	60500	56000	52000	48400	45400
	400 000	636000	162000	144000	129000	118000	108000	100000	92700	86500	81000	72000	64500	59000	54000	50000	46300	43200	40500
	350 000	556 500	140000	125000	112000	102000	93500	86500	80500	75000	70300	62500	56000	51000	46750	43200	40200	37500	35100
	300000	477 000	120000	107000	96800	87500	80000	74000	68700	64000	60000	53500	48000	43700	40000	37000	34300	32000	30000
	250000	397 500	100000	89300	80500	73000	67000	62000	57500	53700	50200	44600	40200	36500	33500	31000	28700	26800	25100
0000	211 600	336 420	85000	75500	68000	61800	56700	52300	48500	45300	42500	37700	34000	30900	28300	26100	24200	22600	21200
		266 800	67700	60200	54200	49300	45200	41700	38700	36100	33900	30100	27100	24600	22600	20800	19300	18000	16900
		211 950	53500	47500	42700	38800	35600	32900	30500	28500	26800	23700	21300	19400	17800	16400	15200	14200	13400

140 000 VOLTS DELIVERED

B & S No.	Copper	Aluminum	64 Miles	72 Miles	80 Miles	88 Miles	96 Miles	104 Miles	112 Miles	120 Miles	128 Miles	144 Miles	160 Miles	176 Miles	192 Miles	208 Miles	224 Miles	240 Miles	256 Miles
	650 000	1 033 000	295000	262000	236000	215000	196000	181000	168000	157000	147000	131000	118000	107000	98000	90500	84000	78500	73500
	600 000	954 000	272000	242000	217000	197000	181000	167000	156000	145000	136000	121000	108000	98500	90500	83500	78000	72500	68000
	550 000	874 500	251000	223000	201000	182000	167000	155000	143000	134000	126000	111000	100000	91000	83500	77500	71500	67000	63000
	500 000	795 000	226000	201000	181000	165000	151000	140000	130000	121000	113000	101000	90700	82500	75600	69800	64800	60500	56700
	450 000	715 500	203000	181000	163000	148000	135000	125000	116000	108000	102000	90400	81400	74000	67800	62600	58100	54200	50800
	400 000	636 000	181000	161000	145000	132000	121000	112000	104000	96900	90800	80800	72700	66100	60600	55900	51900	48400	45400
	350 000	556 500	158000	140000	127000	115000	105000	97400	90400	84400	79100	70300	63300	57500	52700	48700	45200	42200	39600
	300 000	477 000	135000	120000	108000	98500	90300	83400	77400	72200	67700	60200	54200	49300	45100	41700	38700	36100	33800
	250 000	397 500	113000	101000	90700	82500	75600	69800	64800	60500	56700	50400	45400	41200	37800	34900	32400	30200	28300
0000	211 600	336420	95700	85000	76500	69600	63800	58900	54700	51000	47800	42500	38300	34800	31900	29400	27300	25500	23900
		266 800	76200	67700	61000	55400	50800	46900	43500	40600	38100	33800	30500	27700	25400	23400	21800	20300	19000
		211 950	60000	53400	48000	43700	40000	36900	34300	32000	30000	26700	24000	21800	20000	18500	17100	16000	15000

* The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with the table on page 17, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See text.

QUICK ESTIMATING TABLES*

CONDUCTORS

KILOVOLT-AMPERES, 3 PHASE, WHICH MAY BE DELIVERED AT THE FOLLOWING VOLTAGES OVER THE VARIOUS CONDUCTORS FOR THE DISTANCES STATED. BASED UPON THE FOLLOWING I^2R LOSS (EFFECT OF CHARGING CURRENT NEGLECTED)

	AT 25° C	AT 65° C
FOR LOAD POWER-FACTOR OF 100%	8.66% LOSS	10.0% LOSS
FOR LOAD POWER-FACTOR OF 80%	10.8% LOSS	12.5 LOSS

154,000 VOLTS DELIVERED

COPPER AREA IN CIRCULAR MILS	ALUMINUM AREA IN CIRCULAR MILS	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	237 500	219 500	203 500	190 000	178 500	158 500	142 500	129 500	118 500	109 500	102 000	95 000	89 000	79 200	71 200	64 700	59 300
600 000	954 000	219 000	202 000	187 500	175 000	164 000	145 500	131 500	119 500	109 500	101 000	93 500	87 500	82 000	73 000	65 700	59 700	54 700
550 000	874 500	202 000	187 000	173 000	161 500	151 500	134 500	121 300	110 200	101 000	93 300	86 600	80 800	75 700	67 300	60 700	55 200	50 500
500 000	795 000	183 500	169 000	157 000	146 500	137 500	122 000	109 500	99 500	91 500	84 500	78 500	73 200	68 700	61 000	55 000	50 000	45 700
450 000	715 500	164 500	152 000	141 000	131 600	123 500	109 500	98 800	89 800	82 300	76 000	70 600	65 800	61 700	54 800	49 300	44 900	41 200
400 000	636 000	147 000	136 000	126 500	117 500	110 500	98 000	88 300	80 200	73 500	67 800	63 000	58 800	55 200	49 000	44 200	40 200	36 800
350 000	556 500	128 200	118 500	109 500	102 500	96 000	85 300	76 800	69 800	64 000	59 200	54 800	51 200	48 000	42 700	38 500	35 000	32 100
300 000	477 000	109 500	102 000	94 000	87 500	82 000	73 000	65 700	59 700	54 700	50 500	46 800	43 700	41 000	36 500	32 800	29 800	27 300
250 000	397 500	91 500	84 500	78 500	73 200	68 600	61 000	54 800	49 800	45 700	42 200	39 200	36 600	34 300	30 500	27 400	24 900	22 900
	336 420	77 200	71 200	66 200	61 600	57 700	51 500	46 200	42 000	38 500	35 600	33 000	30 800	28 900	25 700	23 200	21 000	19 200
	266 800	61 500	56 800	52 700	49 200	46 100	41 000	36 900	33 600	30 700	28 400	26 400	24 600	23 100	20 500	18 400	16 800	15 400

187,000 VOLTS DELIVERED

COPPER	ALUMINUM	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	350 000	323 000	300 000	280 000	263 000	234 000	210 000	191 000	175 000	161 500	150 000	140 000	131 500	116 500	105 000	95 200	87 500
600 000	954 000	323 000	297 000	277 000	258 000	242 000	215 000	193 500	176 000	161 500	149 000	138 000	129 000	121 000	107 500	97 000	88 000	80 700
550 000	874 500	299 000	275 000	256 000	239 000	224 000	199 000	179 000	162 500	149 000	137 500	128 000	119 500	112 000	99 500	89 500	81 500	74 600
500 000	795 000	270 000	250 000	232 000	216 000	203 000	180 000	162 000	147 500	135 000	125 000	115 500	108 000	101 000	90 000	81 000	73 700	67 600
450 000	715 500	243 000	225 000	209 000	194 500	182 000	162 000	145 500	132 500	121 500	112 000	104 000	97 200	91 000	81 000	73 000	66 200	60 700
400 000	636 000	217 000	200 000	185 500	173 500	162 500	144 500	130 000	118 500	108 500	100 000	93 000	86 700	81 300	72 200	65 000	59 000	54 200
	556 500	189 000	174 500	162 000	151 000	141 500	126 000	113 500	103 000	94 500	87 000	81 000	75 500	70 800	63 000	56 700	51 500	47 200
	477 000	161 000	149 000	138 000	129 000	121 000	107 500	96 500	88 000	80 500	74 300	69 000	64 500	60 500	53 700	48 300	44 000	40 300
	397 500	134 500	124 500	115 500	107 500	101 000	89 800	80 800	73 500	67 300	62 200	57 800	53 800	50 500	44 800	40 400	36 800	33 700
	336 420	114 000	105 000	97 500	91 000	85 200	75 800	68 200	62 000	57 000	52 600	48 800	45 500	42 700	38 000	34 200	31 000	28 500

220,000 VOLTS DELIVERED

COPPER	ALUMINUM	96 MILES	104 MILES	112 MILES	120 MILES	128 MILES	144 MILES	160 MILES	176 MILES	192 MILES	208 MILES	224 MILES	240 MILES	256 MILES	288 MILES	320 MILES	352 MILES	384 MILES
650 000	1 033 000	485 000	447 000	417 000	388 000	364 000	323 000	291 000	265 000	243 000	224 000	208 000	194 000	182 000	162 000	145 500	132 500	121 500
	954 000	447 000	413 000	383 000	358 000	336 000	298 000	268 000	244 000	224 000	207 000	192 000	179 000	168 000	149 000	134 500	122 000	112 000
	874 500	413 000	382 000	354 000	331 000	310 000	276 000	249 000	226 000	207 000	191 000	177 500	165 500	155 000	138 000	124 000	112 800	103 500
	795 000	374 000	345 000	321 000	299 000	281 000	249 000	224 000	204 000	187 000	173 000	160 000	149 500	140 500	124 500	112 500	102 000	93 500
	715 500	336 000	310 000	288 000	269 000	252 000	224 000	202 000	183 500	168 000	155 000	144 000	134 500	126 000	112 000	101 000	92 000	84 200
	636 000	300 000	277 000	257 000	240 000	225 000	200 000	180 000	163 500	150 000	138 500	128 500	120 000	112 500	100 000	90 000	82 000	75 000

* The loss due to corona will not be excessive with any of the above conductors used at sea level for the voltages stated. For elevations above sea level, check the values with the table on page 17, especially for the smaller conductors. On long circuits of high voltage, the effect of charging current (also corona and leakage losses) will be to increase or decrease the I^2R loss, depending on the amount of load and its power-factor. See text.

CHAPTER VII

PERFORMANCE OF SHORT TRANSMISSION LINES

(EFFECT OF CAPACITANCE NOT TAKEN INTO ACCOUNT)

The problems which come under the general heading of short transmission lines are those in which the capacitance of the cicuit is so small that its effect upon the performance of the circuit may, for all practical purposes, be ignored. The effect of capacitance is to produce a current in leading quadrature with the voltage, usually designated as charging current. This leading component of current in the conductor does not appear in the load current at the receiving end of the circuit. It is zero at the receiving end of the circuit but increases at nearly a uniform rate as the sending end of the circuit is approached, at which point it ordinarily becomes a maximúm.

The effect of this charging current flowing through the inductance of the circuit is to increase the receiving-end voltage and therefore to decrease the voltage drop under load. Since the charging current is 2.4 times greater for a frequency of 60 cycles than it is for a frequency of 25 cycles, its effect upon the voltage regulation will be considerably greater at 60 cycles than at 25 cycles. The effect of charging current upon the voltage regulation will also increase as the distance of transmission is increased.

If the circuit were without capacitance, there would be no charging current and consequently the mathematical and the two graphical solutions (impedance methods) which follow under the general heading of "short transmission lines" would all produce accurate results. All circuits, however, have some capacitance, and as the length or the frequency of the circuit increases, these three methods will therefore yield results of increasing inaccuracy. Some engineers consider these impedance methods sufficiently accurate for circuits 20 to 30 miles long while others use them for still longer circuits. To act as a guide, Table *J* indicates the error in the supply voltage as determined by these impedance methods, for circuits of different lengths corresponding to both 25- and 60-cycle frequencies. These three impedance methods produce practically the same results, and the sending end voltage, as determined by any of these methods, is always slightly high. In other words the effect of the charging current is to reduce the voltage necessary at the sending end, for maintaining a certain voltage at the receiving end of the circuit. The error referred to below for the three methods is expressed in percentage of the receiving end voltage. Thus, for a 30-mile, 25-cycle circuit, the error is 0.04 per cent, and for a 30-mile, 60-cycle circuit the error is 0.2 per cent. If an error of 0.5 per cent is considered permissible, then the Dwight or the Mershon Chart methods, or the corresponding mathematical solution, may be used for 25-cycle circuits up to approximately 125 miles, and for 60-cycle circuits up to approximately 50 miles. Of course these impedance methods may be used for still longer circuits by making proper allowance to compensate for the fundamental error.

DIAGRAM ILLUSTRATING A SHORT TRANSMISSION CIRCUIT

Figure 16 illustrates the relation between the various elements in short transmission circuits, when the effect of capacitance and leakage is not taken into account. The current flowing in such a circuit meets two opposing e.m.f's.; *i.e.* of resistance in phase with the current and reactance in lagging quadrature with the current.

The upper part of Fig. 16 illustrates such a circuit schematically and the lower part vectorially. The voltage component required at the sending end to overcome the resistance IR of the circuit is indicated in the vector

TABLE *J*

Length of circuit (miles)	Error in percentage of receiver voltage	
	25 cycles	60 cycles
20	+0.02	+0.10
30	+0.04	+0.2
50	+0.1	+0.5
100	+0.4	+1.9
200	+1.4	+8.0
300	+3.3	+18.0

diagram by a short line parallel with the base line I, representing the phase of the current. These lines are drawn parallel, since the resistance voltage drop is in phase with the current. The voltage component required at the sending end to overcome the reactance IX of the circuit is indicated by a line in quadrature or at right angles, to the phase of the current. The reactance is in quadrature with the current for the reason that the rate of change in the magnetic field (consequently the e.m.f. of self-induction or reactance) surrounding the conductor is greatest when the current is passing through zero. The hypotenuse IZ of this

small right angle impedance triangle represents the impedance voltage of the circuit. It represents the direction and value of the resulting voltage necessary to overcome the combined effect of the resistance and the reactance of the circuit.

The relative values and phases of the receiving and sending end voltages, and their phase relations with the current I, are also indicated on the vector diagram. This diagram is plotted for a receiving end load based upon 80 per cent power-factor lagging. E_s represents the value of the voltage required at the sending end of the circuit to maintain the voltage E_r at the receiving end, when the impedance of the circuit is IZ and the receiving end power-factor is 80 per cent lagging. The phase angle θ_s indicates the amount by which the current lags behind the voltage at the sending end; $\cos\ \theta_s$ being the power-factor of the load as measured at the sending end. Likewise $\cos\ \theta_r$ is the power-factor of the load at the receiving end.

TAPS TAKEN OFF CIRCUIT

Usually the main transmission circuit is tapped and power taken off at one or more points along the circuit. The performance of such a circuit must be calculated by steps thus: Assume a circuit 200 miles long with 10,000 kw. taken off at the middle and 10,000 kw. at the receiving end. From the conditions known or assumed at the receiving end, calculate the corresponding sending end conditions, that is the voltage, power and power-factor at the substation in the middle of the circuit. To the calculated value of the actual power in kilowatts add the losses at the substation in the middle of the circuit. Any leading or lagging component in the substation load current must also be added algebraically, in order to determine the power-factor at the sending side of the substation. This will then be the receiving-end conditions at the substation in the middle of the circuit, from which the corresponding conditions at the sending-end of the circuit may be calculated. If the sending-end conditions are fixed, and the receiving-end conditions are to be determined, the substation losses will in such case be subtracted in place of added.

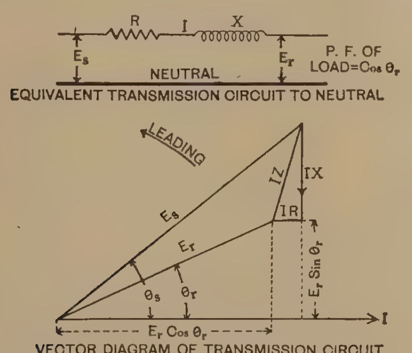


FIG. 16.—Diagrams for short transmission lines. Impedance method, capacitance effect not taken into account.

CABLE AND AERIAL LINES IN SERIES—COMPOSITE LINES

In some cases it is necessary to place part of a transmission circuit underground, and in other cases it may be desirable to use two or more sizes of conductors in series. The result will be that the circuit constants will be different for the various sections. If the effect of capacitance be neglected, the combined circuit may be treated as a single circuit having a certain total resistance R and a total reactance X.

PROBLEMS

Later a table will be presented listing a large number of transmission circuits from 20 to 500 miles long, at both 25 and 60 cycles operating at from 10,000 to 200,000 volts. These problems are numbered from 1 to 64. When a reference is made in the following to some problem number it will refer to one of this list of problems.

SYMBOLS

The symbols which will be employed in the following treatment are given below:

For load conditions

- Kv.a$_r$ = (total) at receiving end.
- Kv.a$_{rn}$ = (one conductor to neutral) at recieving end.
- Kv.a$_s$ = (total) at sending end.
- Kv.a$_{sn}$ = (one conductor to neutral) at sending end.
- Kw$_r$ = Kw. (total) at receiving end.
- Kw$_{rn}$ = Kw. (one conductor to neutral) at receiving end.
- Kw$_s$ = Kw. (total) at sending end.
- Kw$_{sn}$ = Kw. (one conductor to neutral) at sending end.
- E_r = Voltage between conductors at receiving end.
- E_{rn} = Voltage from conductors to neutral at receiving end.
- E_s = Voltage between conductors at sending end.
- E_{sn} = Voltage from conductors to neutral at sending end.
- I_r = Current in amperes per conductor at receiving end.
- I_s = Current in amperes per conductor at sending end.
- Cos θ_r = Power-factor at receiving end.
- Cos θ_s = Power-factor at sending end.

FOR ZERO LOAD CONDITIONS

The symbols corresponding to zero load conditions are as indicated above for load conditions with the addition of a sub zero.

THE FUNDAMENTAL OR LINEAR CONSTANTS

The fundamental, or "linear constants" of the circuit for each conductor per unit length are represented as follows:

- r = Linear resistance in ohms per conductor mile.
- x = Linear reactance in ohms per conductor mile.
- b = Linear capacitance susceptance to neutral in mhos per conductor mile.
- g = Linear leakage conductance to neutral in mhos per conductor mile. (This represents the direct escape of active power through the air between conductors and of active power leakage over the insulators. These losses must be estimated for conditions similar to these of the circuit under consideration. For all lines except those of great length and high voltage it is common practice to disregard the effects of leakage or corona loss and to take g as equal to zero.
- z = Linear impedance = $\sqrt{r^2 + x^2}$
- y = Linear admittance = $\sqrt{g^2 + b^2}$

If the length of each conductor of the circuit in unit length is designated as l we have

rl = Total resistance in ohms per conductor = R
xl = Total reactance in ohms per conductor = X
bl = Total susceptance in mhos per conductor to neutral = B
gl = Total conductance in mhos per conductor to neutral = G

then,

$Z = \sqrt{R^2 + X^2}$ ohms

and, $Y = \sqrt{G^2 + B^2}$ mhos

IR = Voltage necessary to overcome the resistance.
IX = Voltage necessary to overcome the reactance.
IZ = Voltage necessary to overcome the impedance.

METHODS FOR DETERMINING THE CONSTANTS OF THE CIRCUIT

Several different methods for determining the fundamental constants of the circuit are in use. These methods are illustrated below.

Problem.—Find the resistance volts IR and the reactance volts IX in per cent of delivered volts E_r for the following conditions: 100-kw. active power to be delivered at 1,000 volts, three-phase, 60 cycles, over three No. 0000 stranded, hard-drawn, copper conductors, circuit 1 mile long, with a symmetrical delta arrangement of conductors, 2-ft. spacing, the temperature being taken as 25°C.

Resistance of 1 mile of single conductor = 0.277 ohm (from an old table).

Reactance of 1 mile of single conductor = 0.595 ohm (from an old table).

Method No. 1.—When three-phase circuits first came into use, it was customary (and correct), in determining the loss and voltage regulation, to consider them equivalent to two single-phase circuits, each single-phase circuit transmitting one-half the power of the three-phase system. This practice is still followed by some engineers; thus:

$\frac{50,000}{1,000}$ = 50 amp. per conductor for each single-phase circuit.

$\frac{0.277 \times 2 \times 50}{1,000} \times 100 = 2.77$ per cent resistance volts drop of single-phase circuit.

$\frac{0.595 \times 2 \times 50}{1,000} \times 100 = 5.95$ per cent reactance volts drop of single-phase circuit.

Method No. 2 consists of treating the case as a straight three-phase problem. Thus:

$\frac{100,000}{1,000 \times 1.732} = 57.73$ amperes per conductor of three-phase circuit.

$\frac{0.277 \times 1.732 \times 57.73}{1,000} \times 100 = 2.77$ per cent resistance volts drop of three-phase circuit.

$\frac{0.595 \times 1.732 \times 57.73}{1,000} \times 100 = 5.95$ per cent reactance volts drop of three-phase circuit.

Method No. 3 consists in assuming one-third the total power transmitted over one conductor with neutral or ground return (resistance and reactance of return being taken as zero). Such an equivalent circuit is shown by diagram in the upper part of Fig. 16. Thus the circuit constants for the above problem would be determined as follows:

Watts per phase $= \frac{100,000}{3} = 33,333$ watts.

Volts to neutral $= 1,000 \times 0.5774$ or 577.4 volts.

$\frac{33,333}{577.4} = 57.74$ amperes per conductor; (same as for method No. 2)

$\frac{0.277 \times 57.74}{577.4} \times 100 = 2.77$ per cent resistance volts drop of three-phase circuit.

$\frac{0.595 \times 57.74}{577.4} \times 100 = 5.95$ per cent reactance volts drop of three-phase circuit.

It will be seen that all three methods produce the same results. *Method No.* 3 seems the most readily adaptable to various kinds of transmission systems and will be used exclusively in the treatment of the problems which will follow.

APPLICATION OF THE TABLES

Chart II plainly indicates the application of these tables, etc. to the calculation of transmission circuits and the sequence in which they should be consulted.

GRAPHICAL VS. MATHEMATICAL SOLUTIONS

At the time of the design of a transmission circuit the actual maximum load or power-factor of the load that the circuit will be called upon to transmit is seldom known. An unforseen development leading to an increased demand for electrical energy may result in a greatly increased load to be transmitted. The actual length of a circuit (especially when located in a hilly or rolling country) is never known with mathematical accuracy. Moreover, the actual resistance of the conductors varies to a large extent with temperature variations along the circuit.

When it is considered that there are so many indeterminate variables which vitally affect the performance of a transmission circuit, it would seem that a comparatively long and highly mathematical solution for determining the exact performance, necessarily based upon rigid assumptions, is hardly justified. In many cases the economic loss in transmission will determine the size of conductors and, if the circuit is very long, synchronous machinery is likely to be employed for controlling the voltage.

Mathematical solutions have one very important virtue, in that they provide an entirely different but parallel route in the solution of such problems, and therefore are valuable as a check against serious errors in the results obtained by the more simple graphical solutions.

In the following treatment, simple but highly accurate graphical solutions will be first presented, for determining the performance not only of short transmission lines, but also for long lines. For short lines the Dwight and the Mershon charts will be used. For

CHART II.—APPLICATION OF TABLES TO SHORT TRANSMISSION LINES

(Effect of Capacitance Not Taken into Account) Over Head Bare Conductors

Starting with the kv.a., voltage and power-factor at the receiving end known.

QUICK ESTIMATING TABLES

From the quick estimating table corresponding to the voltage to be delivered, determine the size of the conductors corresponding to the permissible transmission loss.

HEATING LIMITATION

If the distance of transmission is short and the amount of power transmitted very large there is a possibility of overheating the conductors—to guard against such overheating the carrying capacity of the conductors contemplated should be checked by the heating tables.

CORONA LIMITATION

If the transmission is at 30,000 volts, or higher, the corona table should be consulted to avoid the employment of conductors having diameters so small as to result in excessive corona loss.

RESISTANCE—TABLES V AND VI

From one of these tables obtain the resistance per unit length of single conductor corresponding to the maximum operating temperature—calculate the total resistance for one conductor of the circuit.

I^2R TRANSMISSION LOSS

Calculate the I^2R loss of one conductor by multiplying its total resistance by the square of the current—to obtain the total loss multiply this result by the number of conductors of the circuit.

REACTANCE—TABLES IX TO XII

From one of these tables obtain the reactance per unit length of single conductor. Calculate the total reactance for one conductor of the circuit. If the reactance is excessive (20 to 30 per cent reactance volts will in many cases be considered excessive) consult Tables XIII to XVI. Having decided upon the maximum permissible reactance the corresponding resistance may be found by dividing this reactance by the ratio value in Tables XIII to XVI. When the reactance is excessive, it may be reduced by installing two or more circuits and connecting them in parallel, or by the employment of three conductor cables. Using larger conductors will not materially reduce the reactance. The substitution of a higher transmission voltage, with its correspondingly less current, will also result in less reactance.

GRAPHICAL SOLUTION

A simple graphical solution, as described in the text, may be made by which the kv.a. the voltage and the power-factor at the sending end of the circuit may be determined graphically. Or the voltage at the sending end may be determined graphically by the use of either the Dwight or the Mershon chart. With the Mershon chart the power-factor at the sending end may be read directly from the chart.

MATHEMATICAL SOLUTION

As a precaution against errors the results obtained graphically should be checked by a mathematical solution, in cases where accuracy is essential.

long lines, where the effect of capacitance must be accurately accounted for, the Wilkinson Charts, supplemented with vector diagrams will be used. These three forms of graphical solutions will, when correctly applied to any power transmission problem, produce results in which the error will be much less than that due to irregularities in line construction and inaccurate assumptions of circuit constants. These three graphical solutions will in each case be followed by mathematical solutions. In the case of short lines the usual formulas employing trigonometric functions will be employed, and in the case of long lines the convergent series, and two different forms of hyperbolic solutions will be employed.

GRAPHICAL SOLUTION

When the receiving end load conditions, that is, the voltage, the load and the power-factor are known, the IR volts required to overcome the resistance and the IX volts required to overcome the reactance the of circuit, may be readily calculated.

On a piece of plain paper or cross-section paper divided into tenths, a vector diagram of the current and of the various voltage drops of the circuit may be laid out to a convenient scale. Whichever kind of paper is used, the procedure will be as in the following example.

Single-phase Problem.—Find the voltage at the sending end of a single-phase circuit 16 miles long, consisting of two stranded, hard-drawn No. 0000 copper conductors spaced 3 ft. apart. Temperatures taken as 25°C. Load conditions at receiving end assumed as 4,000 kv.a. (3,200 kw. at 80 per cent power-factor lagging) 20,000 volts, single-phase, 60 cycles.

$$Kv.a_{rn.} = \frac{4,000}{2} = 2,000 \text{ kv.a. to neutral.}$$

$$E_{rn} = \frac{20,000}{2} = 10,000 \text{ volts to neutral.}$$

$$I_r = \frac{2,000,000}{10,000} = 200 \text{ amperes per conductor.}$$

The fundamental constants per conductor are:—

$$R = 16 \times 0.277 \text{ (from old table)} = 4.432 \text{ ohms}$$

$$X = 16 \times 0.644 \text{ (from old table)} = 10.304 \text{ ohms}$$

and $IR = 200 \times 4.432 = 886$ volts resistance drop

$$= \frac{886}{10,000} \times 100 = 8.86 \text{ per cent}$$

$$IX = 200 \times 10.304 = 2061 \text{ volts reactance drop}$$

$$= \frac{2,061}{10,000} \times 100 = 20.61 \text{ per cent}$$

Having determined the above values a vector diagram may be made as follows:

Draw an arc quadrant having a radius of 10,000 (the receiving end voltage to neutral) to some convenient scale, as shown in Fig. 17. The radius which represents the base, or horizontal line will be assumed

as representing the phase of the current at the receiving end of the circuit. Divide this base line into 10 equal parts. These 10 divisions will then correspond to loads of corresponding power-factors. Since a load has been assumed having a power-factor of 80 per cent lagging, draw a vertical line from the 0.8 division on the base line, until it intersects the arc of the circle. From this point of intersection draw a line to the right and parallel with the base line. To the same scale as that plotted for the receiver voltage (10,000) measure off to the right 886 volts to D. This is the voltage which, as determined above is required to overcome the resistance of one conductor of the circuit. It is sometimes stated as the voltage consumed by the line resistance. It will be noted that this voltage drop is in phase with the current at the receiving end. From this point lay off vertically, and to the same scale, 2,061 volts which is, as determined above, the volts necessary to overcome the reactance of one conductor of the circuit. This is sometimes stated as the voltage consumed by the line reactance. Connect this last point by a straight line with the center E of the arc. The length of this line ES represents the voltage to neutral at the sending end which, for this problem, is 11,998 volts. The distance this line extends beyond the arc represents the drop in voltage for one conductor of the circuit. The voltage drop for this problem is $1{,}998/10{,}000 \times 100 = 19.98$ per cent of the receiving end voltage.

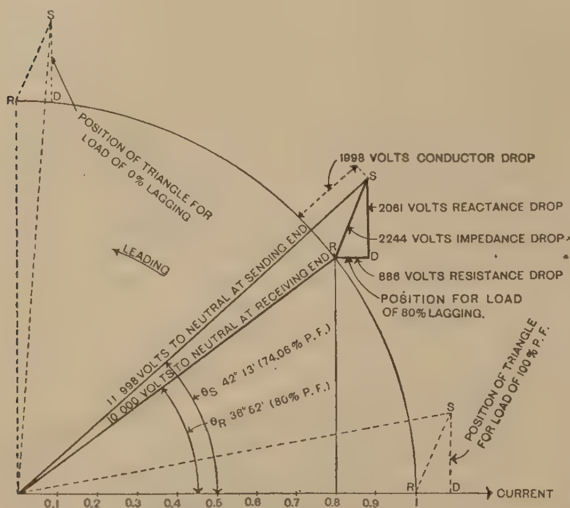


FIG. 17.—Graphical solution for a short transmission line. Capacitance effect not taken into account.

The phase difference between the current and the voltage at the receiver end is $\theta_r = 36° 52'$. This is the angle whose cosine is 0.8 corresponding to a power-factor at the receiving end of 80 per cent. Likewise the phase difference between the receiving end current and the sending end voltage is $\theta_s = 42° 13'$ corresponding to a power-factor at the supply end of 74.06 per cent. The difference in these two phase angles (5° 21′) represents the difference in the phase of the voltages at the sending and receiving ends of the circuit. The power-factor at the sending end of the circuit may be readily obtained by dropping a vertical line down from the point where the line representing the sending end voltage ES intersects the arc of the circle, to the base line representing the phase of the receiving end current. Such a line will correspond to a power-factor of 74.06 per cent. This assumption that the vector representing the direction of the receiving end current also represents the direction of the sending end current is upon the basis that the circuit is without capacitance. It, therefore, is permissible only with short lines.

In Fig. 17 the location of the impedance triangle is also indicated (by broken lines) in positions corresponding to a receiving end load of 100 per cent power-factor; and also for a receiving end load of zero lagging power-factor. It is interesting to note that in the case of 100 per cent power-factor the resistance drop (at right angle to the arc) has maximum effect upon the voltage drop; whereas the reactance drop (nearly parallel with the arc) has a minimum effect upon the voltage drop. At zero lagging power-factor load just the reverse is true; namely the resistance drop is nearly parallel with the arc and causes a minimum voltage drop, while the reactance is at right angles and produces a maximum effect upon the voltage drop.

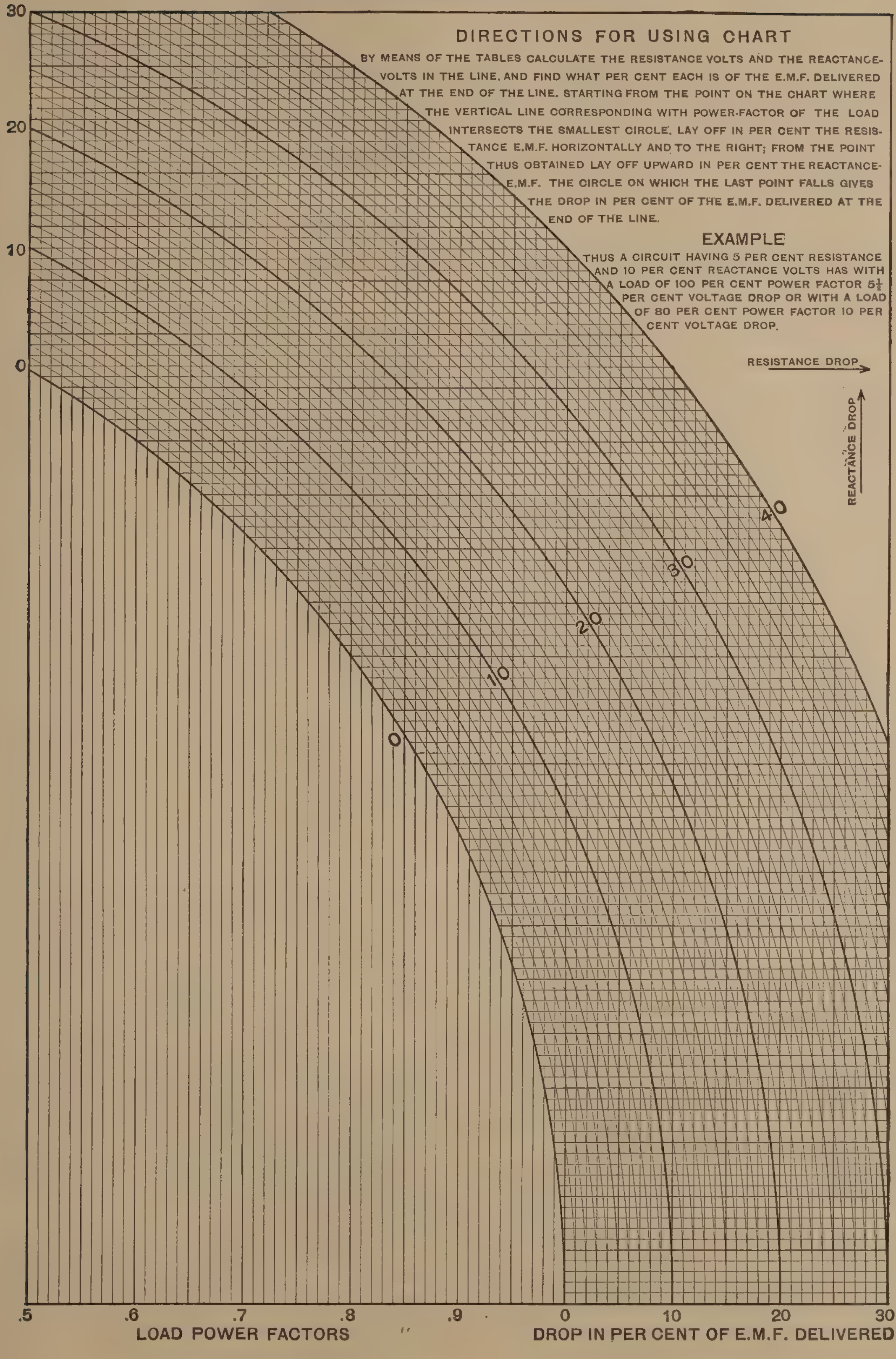
VOLTAGE AT SENDING END AND LOAD AT RECEIVING END FIXED

In cases of feeders to be tapped into main transmission circuits, the voltage at the sending end is usually fixed. It may be desired to determine what the voltage will be at the receiving end corresponding to a given load. This may be obtained graphically as follows:

Draw a horizontal line which will be assumed to represent the phase of the current (Fig. 17). Since the power-factor of the load at the receiving end is known, the angle whose cosine corresponds may be obtained from Table K. This angle represents the phase relation between the current and the voltage at the receiving end of the circuit. For the problem illustrated by Fig. 17 this angle is 36° 52′, corresponding to a power-factor of 80 per cent. Having determined this angle, draw a second radial line intersecting the current vector at the angle corresponding to the receiving end load power-factor. This second line will then represent the direction of the voltage at the receiving end of the circuit. If the load power-factor is lagging, this line will be in the forward direction, and if the load power-factor is leading it will be in the backward direction from the current vector. Now with the intersection of the current and voltage vectors as a center, draw an arc of a circle to some suitable scale, representing the voltage at the sending end. Calculate the voltage necessary to overcome the resistance, and also that necessary to overcome the reactance of the circuit.

Draw a right angle impedance triagle to the same scale, using the resistance volts as a base. Cut out the impedance triangle to its exact size. Keeping the base

CHART III—MERSHON CHART



of the triangle (resistance voltage) in a horizontal position (parallel with the current vector) move the triangle over the diagram in such a manner that its apex follows the arc of the circle representing the numerical value of the voltage at the sending end. Move the triangle up or down until a position is found where it makes connection with the vector representing the voltage at the receiving end. This is then the correct position for the impedance triangle, and the receiving end voltage may be scaled off.

GRAPHICAL SOLUTION BY THE MERSHON CHART

The above graphical solution is that employed in the well-known chart which Mr. Ralph D. Mershon early presented to the electrical profession, and which is reproduced as Chart III. The Mershon Chart is simply a diagram on cross-section paper with vertical and horizontal subdivisions each representing one per cent of receiving end voltage. On this chart a number of concentric arcs are drawn, representing voltage drops up to 40 per cent. After the reactance and the resistance volts have been calculated and expressed in per cent of E_r the impedance triangle is traced upon the chart and the voltage drop in percentage of E_r is read directly as indicated by the directions. All values on the chart are expressed in per cent of the receiving end voltage.

Single-phase Problem.—Taking the resistance voltage as 8.86 per cent and the reactance voltages 20.61 per cent of the receiving end voltage, for the above single-phase problem, (Fig. 17) and tracing these values upon the Mershon Chart for a receiving end load of 80 per cent power-factor lagging, the voltage drop is determined as 19.9 per cent. The calculated value being 19.98 per cent, the error by the chart is seen to be negligible.

WHEN THE SENDING END CONDITIONS ARE FIXED

When the conditions at the sending end are fixed and those at the receiving end are to be determined, the solving of the problem by the Mershon Chart is more complicated. In such cases, it is usual to estimate what the probable receiving end condition will be. From these estimated receiving end conditions, determine by the chart the corresponding sending end conditions. If the conditions as determined by this assumption are materially different from the known conditions, another assumption should be made. The corresponding end conditions should then be checked with the known conditions. Several such trials will usually be necessary to solve such problems.

GRAPHICAL SOLUTION BY THE DWIGHT CHART

Mr. H. B. Dwight has worked up a straight line chart, shown as Chart IV, in which the resistance and the reactance of the circuit have been taken into account through the medium of spacing lines marked for various sizes of conductors.* The use of this chart does not, therefore, require the calculation of the resistance and reactance or the use of tables of such constants. The Dwight Chart is also constructed so as to be applicable to loads of leading as well as to loads of lagging power-factors, whereas the Mershon Chart, as generally constructed, is applicable to loads of lagging power-factor only. However the Mershon Chart can be made applicable for the solving of problems of leading as well as lagging power-factor loads by extending it through the lower right-hand quadrant. The application of synchronous condensers frequently gives rise to loads of leading power-factor. The Dwight Chart is well adapted to the solution of such circuits. Still another feature of this chart is that formulas are given which take capacitance effect into account with sufficient accuracy for circuits with a length up to approximately 100 miles.

Single-phase Problem.—Find the voltage at the sending end of a single-phase circuit 16 miles long, consisting of two-stranded, hard-drawn, No. 0000 copper conductors, spaced 3 ft. apart. Temperature taken as 25°C. Load condition at receiving end assumed as 4,000 kv.a. (3,200 kw. at 80 per cent power-factor lagging) 20,000 volts single-phase, 60 cycles.

From an old table the resistance of No. 0000 stranded, hard-drawn, copper conductors at 25°C. is found to be 0.277 ohm per wire per mile. Lay a straight edge across the Dwight Chart from the resistance value per mile 0.277 (as read on the lower half of the vertical line to the extreme right) to the spacing of 3 ft. for copper conductors and 60 cycles at the extreme left. Along this straight edge read factor $V = 0.62$, corresponding to a lagging power-factor of 80 per cent. This factor V is equivalent to the change in receiving end voltage per total ampere per mile of circuit, due to the line impedance.

It will be noted that opposite the resistance values (extreme right vertical line) is placed the corresponding sizes of copper and aluminum conductors on the basis of a temperature of 20°C. If the temperature is assumed to be 20°C. it will not be necessary to consult a table of resistance values. In such a case, the straight edge would simply be placed over the division of the vertical resistance line corresponding to the size and material of conductors. Marking a resistance value on this vertical line makes the chart adaptable to resistance values corresponding to conductors at any temperature. Had the power factor been leading, in place of lagging, the corresponding resistance point would have been located on the upper half of the vertical resistance line.

Continuing following the directions on the chart for short lines, we obtain the following. Since the circuit is single-phase, use $2V = 1.24$.

$$\text{Voltage drop in per cent of } E_r = \frac{100{,}000 \times 4{,}000 \times 16 \times 1.24}{20{,}000^2} = 19.84 \text{ per cent.}$$

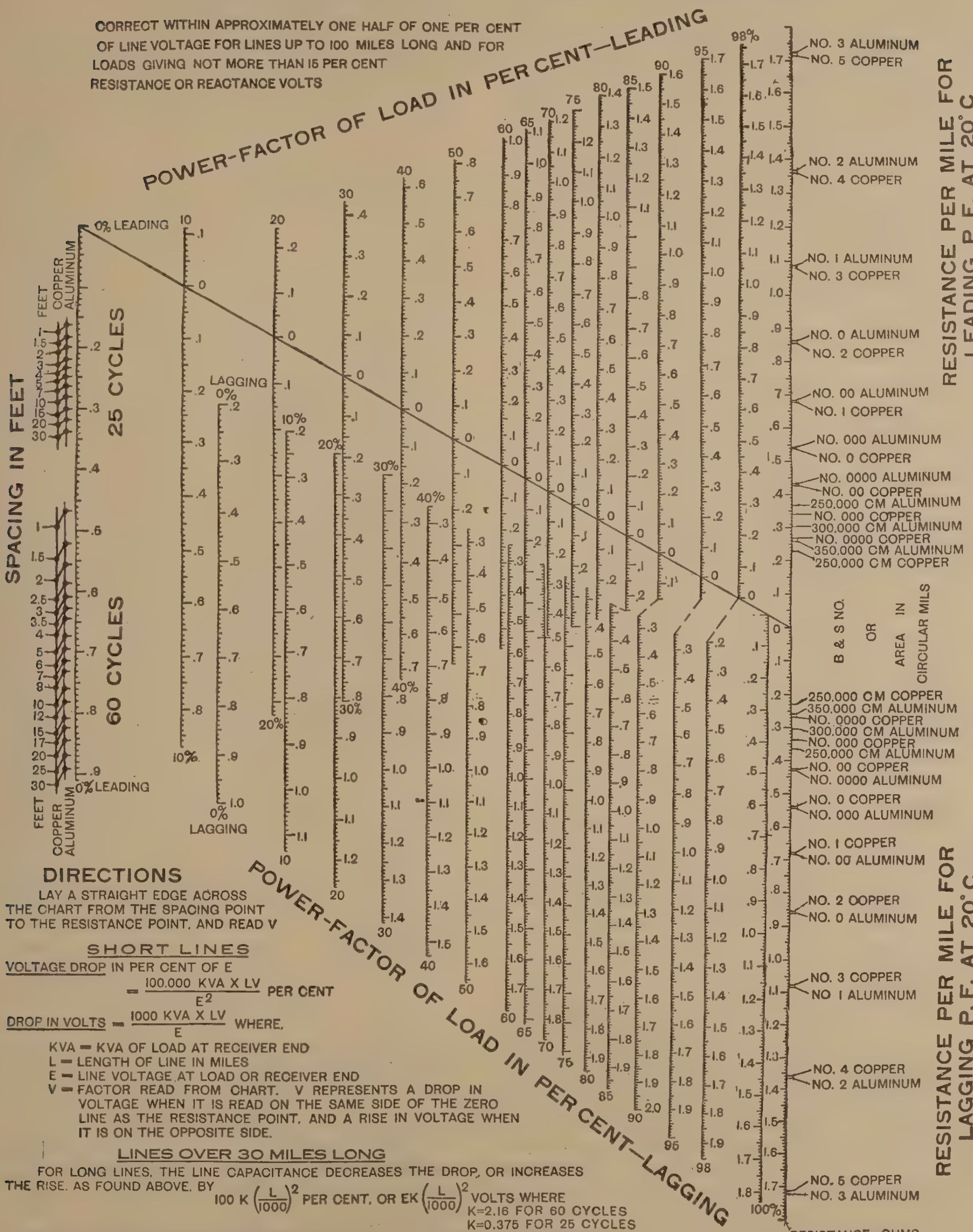
The voltage drop, as calculated mathematically, is 19.98 per cent representing an error of 0.14 per cent by the chart.

*The basis of the construction of this chart is described in the ELECTRIC JOURNAL for July, 1915, p. 306.

CHART IV.—DWIGHT CHART

FOR DETERMINING THE VOLTAGE REGULATION OF TRANSMISSION CIRCUITS CONTAINING CAPACITANCE

CORRECT WITHIN APPROXIMATELY ONE HALF OF ONE PER CENT OF LINE VOLTAGE FOR LINES UP TO 100 MILES LONG AND FOR LOADS GIVING NOT MORE THAN 15 PER CENT RESISTANCE OR REACTANCE VOLTS



DIRECTIONS

LAY A STRAIGHT EDGE ACROSS THE CHART FROM THE SPACING POINT TO THE RESISTANCE POINT, AND READ V

SHORT LINES

VOLTAGE DROP IN PER CENT OF E

$$= \frac{100.000 \text{ KVA X LV}}{E^2} \text{ PER CENT}$$

DROP IN VOLTS $= \frac{1000 \text{ KVA X LV}}{E}$ WHERE,

KVA = KVA OF LOAD AT RECEIVER END
L = LENGTH OF LINE IN MILES
E = LINE VOLTAGE AT LOAD OR RECEIVER END
V = FACTOR READ FROM CHART. V REPRESENTS A DROP IN VOLTAGE WHEN IT IS READ ON THE SAME SIDE OF THE ZERO LINE AS THE RESISTANCE POINT, AND A RISE IN VOLTAGE WHEN IT IS ON THE OPPOSITE SIDE.

LINES OVER 30 MILES LONG

FOR LONG LINES, THE LINE CAPACITANCE DECREASES THE DROP, OR INCREASES THE RISE, AS FOUND ABOVE, BY $100\,K\left(\frac{L}{1000}\right)^2$ PER CENT, OR $EK\left(\frac{L}{1000}\right)^2$ VOLTS WHERE
K=2.16 FOR 60 CYCLES
K=0.375 FOR 25 CYCLES

THE EFFECTIVE SPACING OF 3 PHASE LINES IS $S = \sqrt[3]{ABC}$ S = 1.26 A FOR FLAT SPACING.

THE ABOVE EQUATIONS ARE FOR 2 AND 3 PHASE LINES.
FOR SINGLE PHASE USE 2 V IN PLACE OF V

Three-phase Problem (*No.* 33).—Find the voltage at the sending end of a three-phase circuit, 20 miles long, consisting of three No. 0000 stranded, hard-drawn, copper conductors, spaced 3 ft. apart in a delta arrangement. Temperature taken as 25°C. Load conditions at receiving end assumed as 1,300 kv.a. (1,040 kw. at 80 per cent power-factor lagging) 10,000 volts, three-phase, 60 cycles.

From an old table, the resistance per wire per mile is again found to be 0.277 ohm and since the spacing and frequency are both the same as in the case of the above single-phase problem, we again obtain $V = 0.62$. The voltage drop in per cent of E_r is therefore

$$\frac{100{,}000 \times 1{,}300 \times 20 \times 0.62}{10{,}000^2} = 16.12 \text{ per cent}$$

The voltage drop as calculated mathematically is 16.16 per cent, representing an error of 0.04 per cent.

CAPACITANCE

In long circuits the effect of capacitance is to decrease the voltage drop, or increase the voltage rise, as will be explained later. The Dwight and Mershon Charts do not recognize the effect which capacitance has upon the voltage drop. In the lower left-hand corner of the Dwight Chart, however, there is placed a formula by which a correction may be applied to the voltage drop as given by the chart. This correction accounts for the effect of the charging current (resulting from capacitance) quite accurately, provided the circuit is not too long or the frequency too high. The application of this corrective factor will be evident from the following problem.

Three-phase Problem (No. 45).—Find the voltage at the sending end of a three-phase circuit, 100 miles long, consisting of three No. 0000, stranded, hard-drawn copper conductors, spaced 9 ft. apart in a delta arrangement. Temperature assumed as 25°C. Load conditions at receiving end assumed as 22,000 kv.a., 80 per cent power-factor lagging, 88,000 volts, 60 cycles.

From an old table the resistance is found to be 0.277 ohm per mile. From Dwight Chart read $V = 0.70$. Then, the voltage drop in per cent of E_r, if the line were short, would be

$$\frac{100{,}000 \times 22{,}000 \times 100 \times 0.70}{88{,}000^2} = 19.89 \text{ per cent}$$

From directions on the Dwight Chart for circuits over 30 miles long, the charging current of this circuit is found to be such as to decrease the voltage drop under load conditions or to increase the voltage at zero load by the amount of $100 \times 2.16\ (100/1{,}000)^2 = 2.16$ per cent. Hence the voltage at the sending end, under load conditions, will be $19.89 - 2.16 = 17.73$ per cent. The actual result as calculated rigorously is 17.94 per cent. Thus the error by the Dwight graphical solution is approximately 0.21 per cent.

If the power-factor of the load is assumed as 100 per cent (problem 46) in place of 80 per cent lagging, we get $V = 0.33$ and find the error for the Dwight graphical solution of this 100-mile, 60-cycle circuit to be approximately 0.75 per cent. It should be noted, however, that the reactance volts are in this case 22 per cent of the receiving end voltage.

TABLE K.—COSINES, SINES AND TANGENTS

Angle	Cos θ (P.F.)	Sin θ	Tan θ
0° 00′	1.000	0.0000	0.0000
8° 06′	0.990	0.1409	0.1423
11° 28′	0.980	0.1988	0.2028
14° 04′	0.970	0.2430	0.2506
16° 15′	0.960	0.2798	0.2915
18° 11′	0.950	0.3120	0.3285
19° 56′	0.940	0.3410	0.3627
21° 33′	0.930	0.3673	0.3949
23° 04′	0.920	0.3918	0.4258
24° 29′	0.910	0.4144	0.4554
25° 50′	0.900	0.4357	0.4841
27° 07′	0.890	0.4558	0.5121
28° 21′	0.880	0.4748	0.5396
29° 32′	0.870	0.4929	0.5665
30° 41′	0.860	0.5103	0.5934
31° 47′	0.850	0.5267	0.6196
32° 51′	0.840	0.5424	0.6457
33° 54′	0.830	0.5577	0.6720
34° 54′	0.820	0.5721	0.6976
35° 54′	0.810	0.5864	0.7239
36° 52′	0.800	0.6000	0.7499
37° 48′	0.790	0.6129	0.7757
38° 44′	0.780	0.6257	0.8021
39° 38′	0.770	0.6379	0.8283
40° 32′	0.760	0.6499	0.8551
41° 24′	0.750	0.6613	0.8816
42° 16′	0.740	0.6726	0.9089
43° 06′	0.730	0.6833	0.9358
43° 56′	0.720	0.6938	0.9634
44° 45′	0.710	0.7040	0.9913
45° 34′	0.700	0.7141	1.0199
46° 22′	0.690	0.7238	1.0489
47° 09′	0.680	0.7331	1.0780
47° 55′	0.670	0.7422	1.1074
48° 42′	0.660	0.7513	1.1383
49° 27′	0.650	0.7598	1.1688
50° 12′	0.640	0.7683	1.2002
50° 57′	0.630	0.7766	1.2327
51° 41′	0.620	0.7846	1.2655
52° 24′	0.610	0.7923	1.2985
53° 07′	0.600	0.8000	1.3327
53° 50′	0.590	0.8073	1.3680
54° 32′	0.580	0.8145	1.4037
55° 14′	0.570	0.8215	1.4406
55° 56′	0.560	0.8284	1.4788
56° 37′	0.550	0.8350	1.5175
57° 18′	0.540	0.8415	1.5577
57° 59′	0.530	0.8479	1.5993
58° 40′	0.520	0.8542	1.6426
59° 20′	0.510	0.8601	1.6864
60° 00′	0.500	0.8660	1.7320
60° 39′	0.490	0.8716	1.7783
61° 18′	0.480	0.8771	1.8265
61° 57′	0.470	0.8825	1.8768

SENDING END CONDITIONS FIXED

When the sending end conditions are fixed, a different form of solution must be employed to determine the size of conductors corresponding to a given voltage drop. In such cases, the Dwight Chart is particularly

applicable. To use the chart for the solution of such problems proceed as follows. First V is calculated by means of the formulas on the chart, and then a straight edge is placed through V (on the line corresponding to the power-factor of the load) and the point for the spacing and frequency to be used, and the required size of conductor can be seen at a glance on the resistance scale at the right. To make this application of the chart clear, the following is given,

Voltage drop in per cent of E_r =

$$\frac{100{,}000 \text{ kv.a.} \times LV}{E_r^2} \quad (28)$$

Hence

$$V = \frac{\text{Voltage drop in per cent of } E_r \times E_r^2}{100{,}000 \text{ kv.a.} \times L} \quad (29)$$

Applying (29) to the above problem No. 33 we get

$$V = \frac{16.12 \times 10{,}000^2}{100{,}000 \times 1{,}300 \times 20} = 0.62$$

Following the above directions, the resistance per mile is found to be 0.277 ohm and the corresponding size of conductor No. 0000 copper.

MATHEMATICAL SOLUTION

In order to check any one, or all of the above described graphical methods, a complete mathematical solution may be made by applying the various trigonometrical formulas, Fig. 18, to the values of the problem under consideration. These formulas have been arranged to meet the conditions of loads of either lagging or leading power-factors, and for conditions fixed at either the receiving or the sending ends.

There are numerous problems requiring a solution where the voltage at the sending end, and the kilowatts and the power-factor of the load at the receiving end are fixed. In such cases it is required to determine the corresponding receiving end voltage. This determination can be made mathematically, but such a solution is tedious, since the formulas applying to such cases are cumbersome. Formulas are given at the bottom of Fig. 18 which may be applied to such problems. Time and labor may, however, be saved in solving such problems by the employment of a cut-and-try method usually used in such cases, as follows:

Assume what the voltage drop will be, corresponding to the size of conductors likely to be used. On the basis of this assumption the receiving end voltage is fixed; thus, all of the receiving end conditions are assumed to be fixed. The corresponding sending end voltage is then readily determined by one of the graphical methods described. If the sending end voltage thus determined is found to be materially different from the fixed sending end voltage, another trial, based upon a different receiving end voltage, will probably suffice.

Single-phase Problem.—Find the characteristics of the load at the sending end of a single-phase circuit, 16 miles long, consisting of two stranded, hard-drawn, copper conductors, spaced 3 ft. apart; temperature taken as 25°C.; load conditions at receiving end assumed as 4,000 kv.a. (3,200 kw. at 80 per cent power-factor lagging) 20,000 volts, 60 cycles; transmission loss to be approximately 10 per cent.

Following the procedure given in Chart II, consult the Quick Estimating Table for a delivered voltage of 20,000. Since the conditions of the above problem are a power-factor of 80 per cent, and a temperature 25°C. the corresponding kv.a. values are as indicated at the end of the table on the basis of 10.8 per cent loss in transmission for a three-phase circuit. For a single-phase circuit the corresponding values will be one-half the table values. Thus the 4,000 kv.a. single-phase circuit of the problem is equivalent to 8,000 kv.a. three-phase on the table. From the table, it is seen that for a distance of 16 miles 7,810 kv.a. three-phase can be transmitted over No. 0000 conductors with a loss of 10.8 per cent. 7,810 kv.a. is near enough to 8,000 kv.a. and the loss of the 10.8 per cent is near enough to an assumed loss of 10 per cent, so we decide that No. 0000 copper conductors come nearest to the proper size to meet the conditions of the problem. The loss with No. 0000 conductors will be 8,000/7,810 × 10.8 = 11.06 per cent, as will be shown later.

The table on page 186 indicates that there will be no overheating of this size of conductor.

The table on page 17 indicates that 20,000 volts is too low to result in corona loss with No. 0000 conductors, at any reasonable altitude. Then,

$$\text{Kv.a}_{rn.} = \frac{4{,}000}{2} = 2{,}000 \text{ kv.a. to neutral.}$$

$$\text{Kw}_{rn} = \frac{3{,}200}{2} = 1{,}600 \text{ kw. to neutral.}$$

$$E_{rn} = \frac{20{,}000}{2} = 10{,}000 \text{ volts to neutral.}$$

$$I_r = \frac{2{,}000{,}000}{10{,}000} = 200 \text{ amperes per conductor.}$$

The resistance per conductor is

R = 16 × 0.277 (from an old table) = 4.432 ohms.

The reactance per conductor is

X = 16 × 0.644 (from an old table) = 10.304 ohms.

and

IR = 200 × 4.432 = 866 volts, resistance drop

$$= \frac{886}{10{,}000} \times 100 = 8.86 \text{ per cent}$$

IX = 200 × 10.304 = 2,061 volts, reactance drop

$$= \frac{2{,}061}{10{,}000} \times 100 = 20.61 \text{ per cent}$$

$$E_{sn} = \sqrt{(10{,}000 \times 0.8 + 866)^2 + (10{,}000 \times 0.6 + 2{,}061)^2}$$
$$= 11{,}998 \text{ volts to neutral} \quad (30)$$

$$\theta_s = \tan^{-1}\left(\frac{(10{,}000 \times 0.6) + 2{,}061}{(10{,}000 \times 0.8) + 886}\right) = 42° \, 13' \quad (31)$$

$$\text{Per cent } P.F._s = (\text{Cos } 42° \, 13') \times 100 = 74.06 \text{ per cent} \quad (32)$$

$$\text{Kv.a.}_{sn} = \frac{200 \times 11{,}998}{1000} = 2{,}399.6 \text{ kv.a. per conductor} \quad (33)$$

$$\text{Kw}_{sn} = 2{,}399.6 \times 0.7406 = 1{,}777.1 \text{ kw. per conductor} \quad (34)$$

$$\text{Per cent voltage drop} = \frac{11{,}998 - 10{,}000}{10{,}000} \times 100 = 19.98 \text{ per cent} \quad (46)$$

$$\text{Transmission loss} = \frac{(200)^2 \times 4.432}{1{,}000} = 177.28 \text{ kw. per conductor} \quad (47)$$

$$\text{Per cent transmission loss} = \frac{177.28 \times 2}{3{,}200} \times 100 = 11.08 \text{ per cent} \quad (48)$$

Three-phase Problem (No. 33).—Find the characteristics of the load at the sending end of a three-phase circuit 20 miles long, consisting of three-stranded,

hard-drawn, copper conductors, spaced in a 3-ft. delta. Temperature taken as 25°C. Load conditions at receiving end assumed as 1,300 kv.a. (1,040 kw. at 80 per cent power-factor lagging) 10,000 volts, 60 cycles; transmission loss not to exceed 10 per cent.

Following the procedure given in Chart II, the following results are obtained:

Consult quick estimating table for a delivered voltage of 10,000 volts. Since the conditions of the above problems are, power-factor of load 80 per cent, temperature 25°C. the corresponding three-phase kv.a. values of the table are on the basis of 10.8 per cent loss in transmission. From quick estimating tables it is seen that 1,240 kv.a. three-phase can be transmitted over No. 000 conductors, or 1,560 kv.a., three-phase over No. 0000 conductors at 10.8 per cent loss. Since the loss for the problem is not to exceed 10 per cent and 1,300 kv.a. is to be transmitted, we will select No. 0000 conductors. The loss for these conductors will therefore be 1,300/1,560 of 10.8, or 9 per cent as will be shown later.

The table on page 186 indicates that there will be no over-heating of this size of conductor when carrying 1,300 kv.a. three-phase.

The table on page 17 indicates that 10,000 volts is too low to result in corona loss with No. 0000 conductors at any reasonable altitude. Then:

$$\text{Kv.a}_{rn.} = \frac{1,300}{3} = 433.33 \text{ kv.a. to neutral.}$$

$$\text{Kw}_{rn.} = \frac{1,040}{3} = 346.6 \text{ kw. to neutral.}$$

$$E_{rn} = \frac{10,000}{1.732} = 5,774 \text{ volts to neutral.}$$

$$I_r = \frac{433,333}{5,774} = 75.05 \text{ amperes per conductor.}$$

The resistance per conductor is

$$R = 20 \times 0.277 \text{ (from an old table)} = 5.54 \text{ ohms.}$$

The reactance per conductor is

$$X = 20 \times 0.644 \text{ (from an old table)} = 12.88 \text{ ohms.}$$

$$IR = 75.05 \times 5.54 = 415.8 \text{ volts, resistance drop.}$$

$$= \frac{415.8}{5,774} \times 100 = 7.20 \text{ per cent.}$$

$$IX = 75.05 \times 12.88 = 966.6 \text{ volts, reactance drop.}$$

$$= \frac{966.6}{5,774} \times 100 = 16.74 \text{ per cent.}$$

$$E_{sn} = \sqrt{(5,774 \times 0.8 + 415.8)^2 + (5,744 \times 0.6 + 966.6)^2} = 6707 \text{ volts to neutral} \qquad (30)$$

$$\theta_s = \tan^{-1}\left(\frac{5,774 \times 0.6 + 966.6}{5,774 \times 0.8 + 415.8}\right) = 41° \, 22' \qquad (31)$$

$$PF_s = (\text{Cos } 41° \, 22') \times 100 = 75.05 \text{ per cent} \qquad (32)$$

$$\text{Kv.a}_{sn.} = \frac{75.05 \times 6,707}{1,000} = 503.4 \text{ kv.a. per conductor} \qquad (33)$$

$$\text{Kw}_{sn.} = 503.4 \times 0.7507 = 377.8 \text{ kw. per conductor} \qquad (34)$$

$$\text{Per cent voltage drop} = \frac{6,707 - 5,774}{5,774} \times 100 = 16.16 \text{ per cent} \qquad (46)$$

$$\text{Transmission loss} = \frac{(75.05^2) \times 5.54}{1,000} = 31.20 \text{ kw. per conductor} \qquad (47)$$

$$\text{Per cent transmission loss} = \frac{31.20 \times 3}{1,040} \times 100 = 9.00 \text{ per cent}$$

MIXED SENDING AND RECEIVING END CONDITIONS FIXED

Branch circuits are frequently run from the main transmission trunk circuit to the center of some local distribution. In such cases the voltage at the sending end and the current or the power and power-factor at the receiving end are approximately fixed. In such cases the calculation for the voltage at the receiving end requires more arithmetical work than is required when all the conditions at one end of the circuit are fixed. Such problems can be more readily solved graphically, as previously explained, but may be solved mathematically by applying formula (44) or (45), Fig. 18.

To illustrate the application of formula (44) we will apply the values of problem 33 to formula (44) and calculate the receiving end voltage. Thus we have as fixed conditions:

$$E_{sn} = 6,707 \text{ volts}$$
$$I_r = 75.05 \text{ amperes}$$
$$\text{Cos } \theta_r = 0.8$$
$$\text{Sin } \theta_r = 0.6$$
$$R = 5.54 \text{ ohms}$$
$$X = 12.88 \text{ ohms}$$
$$IR = 415.8 \text{ volts}$$

Then

$$E_r = -75.05\,(5.54 \times 0.8 + 12.88 \times 0.6) + \sqrt{6,707^2 - 75.05^2\,(5.54^2 \times 0.6^2 + 12.88^2 \times 0.8^2) + 2 \times 75.05^2 \times 5.54 \times 12.88 \times 0.8 \times 0.6} \qquad (44)$$

$$= -913 + \sqrt{44,983,849 - 660,242 + 385,831}$$
$$= -913 + 6,637 = 5,774 \text{ volts.}$$

To illustrate the application of formula (45) we will apply the values of problem 33 to formula (45)

Table L.—Illustrating Variation in Reactance Resulting from Changes in the Conductors and Transmission Voltages

Conductors	Total I^2R loss (kw.)	IR Volts	IR Per cent	IX Volts	IX Per cent	Approximate voltage regulation at 100 per cent power factor	Approximate voltage regulation at 80 per cent power factor (lag)
Receiving End Voltage—6,600							
Single circuit of three 500,000 circ. mil bare overhead conductors..	129	123	3.22	622	16.32	4.5	12.8
Two circuits each of three 250,000 circ. mil bare overhead conductors................	129	123	3.22	333	8.73	3.6	7.7
One circuit of 500,000 circ. mil three-conductor cable. Insulation thickness 13/64 by 13/64 inches..............	129	123	3.22	172	4.52	3.2	5.0
Receiving End Voltage—13,200							
Single circuit of three 125,000 circ. mil bare overhead conductors...	129	247	3.22	354	4.64	3.2	5.1

and calculate the receiving end voltage. Thus we have as fixed conditions:

$$E_{sn} = 6{,}707 \text{ volts}$$
$$\mathrm{Kw}_{rn.} = 346.6 \text{ kw.}$$
$$R = 5.54 \text{ ohms}$$
$$X = 12.88 \text{ ohms}$$
$$\cos\theta_r = 0.8$$
$$\sin\theta_r = 0.6$$
$$A = 6{,}707\sqrt{0.5 - \frac{1{,}000 \times 346.6(5.54 \times 0.8 + 12.88 \times 0.6)}{6{,}707^2 \times 0.8}}$$

then

$$E_{rn} = A\sqrt{1 + \sqrt{1 - \frac{(5.54^2 + 12.88^2)346.6^2 \times 10^6}{A^4 \times 0.8^2}}} \qquad (45)$$

$$A = 6{,}707\sqrt{0.5 - 0.1172} = 4{,}152$$
$$E_{rn} = 4{,}152\sqrt{1 + 0.936} = 5{,}774 \text{ volts}$$

$$R = 5.54 \text{ ohms}$$
$$X = 12.88 \text{ ohms}$$
$$L = 346{,}600 \times 5.54 + 260{,}000 \times 12.88 = 5{,}270{,}000$$
$$M = 346{,}600 \times 12.88 - 260{,}000 \times 5.54 = 3.025{,}000$$
$$E^2 = 0.5E_s^2 - L + 0.5\sqrt{E_s^4 - 4E_s^2L - 4M^2}$$
$$E = 5{,}774 \text{ volts}$$

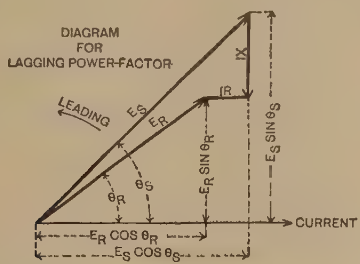
or

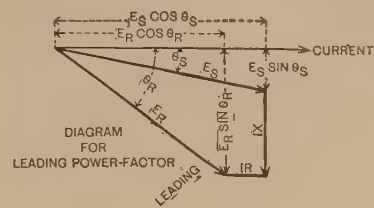
$$E = E_s - \frac{L}{E_s} - \frac{L^2}{E_s^3} - \frac{M^2}{2E_s^3} - \frac{2L^3}{E_s^5} - \frac{3}{2}\frac{LM^2}{E_s^5} - \frac{5L^4}{E_s^7} - \frac{5L^2M^2}{E_s^7} - \frac{5}{8}\frac{M^4}{E_s^7}\,*$$

$$E = 5{,}779 \text{ volts}$$

CIRCUITS OF EXCESSIVE REACTANCE

If a large amount of power is to be transmitted at comparatively low voltage, particularly if the frequency is high, the reactance of the circuit will be high com-





LOADS OF LAGGING POWER-FACTOR

WHEN RECEIVING–END CONDITIONS ARE FIXED

$$E_S = \sqrt{(E_R\cos\theta_R + IR)^2 + (E_R\sin\theta_R + IX)^2} \qquad (30)$$
$$\theta_S = \tan^{-1}\frac{(E_R\sin\theta_R) + IX}{(E_R\cos\theta_R) + IR} \qquad (31)$$
$$\%\,PF_S = \cos\theta_S \times 100 \qquad (32)$$
$$KV\text{-}A_{SN} = \frac{I \times E_{SN}}{1000} \text{ PER CONDUCTOR} \qquad (33)$$
$$KW_{SN} = KV\text{-}A_{SN} \times \cos\theta_S \text{ PER CONDUCTOR} \qquad (34)$$

WHEN SENDING–END CONDITIONS ARE FIXED

$$E_R = \sqrt{(E_S\cos\theta_S - IR)^2 + (E_S\sin\theta_S - IX)^2} \qquad (35)$$
$$\theta_R = \tan^{-1}\frac{(E_S\sin\theta_S) - IX}{(E_S\cos\theta_S) - IR} \qquad (36)$$
$$\%\,PF_R = \cos\theta_R \times 100 \qquad (37)$$
$$KV\text{-}A_{RN} = \frac{I \times E_{RN}}{1000} \text{ PER CONDUCTOR} \qquad (38)$$
$$KW_{RN} = KV\text{-}A_{RN} \times \cos\theta_R \text{ PER CONDUCTOR} \qquad (39)$$

LOADS OF LEADING POWER-FACTOR

WHEN RECEIVING–END CONDITIONS ARE FIXED

$$E_S = \sqrt{(E_R\cos\theta_R + IR)^2 + (E_R\sin\theta_R - IX)^2} \qquad (40)$$
$$\theta_S = \tan^{-1}\frac{(E_R\sin\theta_R) - IX}{(E_R\cos\theta_R) + IR} \qquad (41)$$
$$\%\,PF_S = \cos\theta_S \times 100 \qquad (32)$$
$$KV\text{-}A_{SN} = \frac{I \times E_{SN}}{1000} \text{ PER CONDUCTOR} \qquad (33)$$
$$KW_{SN} = KV\text{-}A_{SN} \times \cos\theta_S \text{ PER CONDUCTOR} \qquad (34)$$

WHEN SENDING–END CONDITIONS ARE FIXED

$$E_R = \sqrt{(E_S\cos\theta_S - IR)^2 + (E_S\sin\theta_S + IX)^2} \qquad (42)$$
$$\theta_R = \tan^{-1}\frac{(E_S\sin\theta_S) + IX}{(E_S\cos\theta_S) - IR} \qquad (43)$$
$$\%\,PF_R = \cos\theta_R \times 100 \qquad (37)$$
$$KV\text{-}A_{RN} = \frac{I \times E_{RN}}{1000} \text{ PER CONDUCTOR} \qquad (38)$$
$$KW_{RN} = KV\text{-}A_{RN} \times \cos\theta_R \text{ PER CONDUCTOR} \qquad (39)$$

GENERAL FORMULAS

WHEN THE VOLTAGE AT SENDING END AND THE AMPERES AND POWER-FACTOR AT RECEIVINGEND ARE FIXED

$$E_R = -I(R\cos\theta_R \pm^{\star} X\sin\theta_R) + \sqrt{E_S^2 - I^2(R^2\sin^2\theta_R + X^2\cos^2\theta_R) \pm^{\star} 2I^2RX\cos\theta_R\sin\theta_R} \qquad (44)$$

★ USE + WHEN THE POWER-FACTOR OF THE LOAD IS LAGGING AND – WHEN THE POWER-FACTOR IS LEADING.

WHEN THE VOLTAGE AT SENDING END AND THE POWER AND POWER-FACTOR AT RECEIVING END ARE FIXED (POWER FACTOR LAGGING)

$$E_{RN} = A\sqrt{1 \pm \sqrt{1 - \frac{(R^2 + X^2)KW_{RN}^2 \times 10^6}{A^4\cos^2\theta_R}}} \quad \text{WHERE } A = E_{SN}\sqrt{\frac{1}{2} - \frac{1000\,KW_{RN}(R\cos\theta_R + X\sin\theta_R)}{E_{SN}^2\cos\theta_R}} \qquad (45)$$

$$\%\text{ VOLTAGE DROP} = \frac{E_S - E_R}{E_R} \times 100 \qquad (46)$$
$$\text{TRANSMISSION LOSS} = \frac{I^2R}{1000} \text{ KW PER CONDUCTOR} \qquad (47)$$
$$\%\text{ TRANSMISSION LOSS} = \frac{\text{TOTAL } I^2R \text{ (IN KW)}}{\text{TOTAL } KW_R} \times 100 \qquad (48)$$

FIG. 18.—Trigonometrical formulas for short transmission lines. Capacitance effect not taken into account.

Alternative to (44) *and* (45).—The following formulas have been proposed by Mr. H. B. Dwight to meet the mixed conditions referred to,

$$E_{sn} = 6{,}707 \text{ volts}$$
$$1{,}000 \times \mathrm{kw}_{rn.} = 346{,}600 \text{ watts}$$
$$1{,}000 \times \text{reactive kv.}a_{rn.} = 346{,}600 \times \frac{0.6}{0.8} = 260{,}000 \text{ v.a.}$$

pared with its resistance. If the reactance is excessive (20 to 30 per cent reactance volts may in some cases be

* Mr. H. B. Dwight: Effect of a Tie Line between Two Substations, *Electrical Review*, Dec. 21, 1918, p. 966. The formulas given in this article make complete allowance for the effect of capacitance and are very similar to the above.

considered excessive), the voltage regulation of the circuit may be seriously impaired.

As will be seen by consulting Tables XIII to XVI, there is a fixed relation between the reactance and the resistance of a circuit for a given frequency, size and spacing of conductors. This ratio is 2.4 times greater for 60-cycle than it is for 25-cycle circuits. For a given size of conductor the reactance can be varied only slightly by changing the spacing of overhead bare conductors. Substituting a larger or smaller conductor may change the resistance materially, but this will have little effect upon the reactance.

The reactance may be reduced by either or all of the following methods. The circuit may be split up into two or more circuits employing smaller conductors and these circuits connected in parallel. The voltage may be raised, if the installation is new, and smaller conductors employed; or the overhead conductors may be replaced by three conductor cables. To illustrate the above methods, the following problem has been assumed and the results tabulated.

A HIGH REACTANCE PROBLEM

Table *L* refers to the following problem—4,000 kv.a., three-phase, 60 cycles, is to be delivered a distance of 3 miles over hard-drawn, stranded copper conductors. The I^2R loss is to remain at 129 kw. The spacing of the overhead conductors assumed as 3 by 3 by 3 ft. Temperature 25°C.

It is evident from Table *L* that if two three-phase circuits, each consisting of three 250,000 circ. mil conductors are installed in place of one three-phase circuit, consisting of three 500,000 circ. mil conductors, the reactance will be reduced by nearly one-half, and a corresponding improvement in the voltage drop or regulation will occur, particularly if the load power-factor is 80 per cent lagging. A further improvement along this line will be obtained if a single three-conductor cable is employed. Doubling the voltage for the overhead circuit and employing three 125,000 circ. mil conductors results in practically as good performance in voltage regulation as for the 6,600 volt three-conductor cable.

CHAPTER VIII

PERFORMANCE OF LONG TRANSMISSION LINES BY GRAPHICAL METHODS

The e.m.f. of self-induction in a transmission circuit may either add to or subtract from the impressed voltage at the sending end, depending upon the relative phase relations between the current and the voltage at the receiving end of the circuit. This is illustrated by means of voltage vectors in Fig. 20, in which the phase of the current is assumed to be constant in the horizontal direction indicated by the arrow on the end of the current vector. The voltage at the receiving end is also assumed as constant at 100 volts. The vector representing the receiving-end voltage (E_r = 100 volts) is shown in two positions corresponding to leading current, two positions corresponding to lagging current and in one position corresponding to unity power-factor. The components IR and IX of the supply voltage necessary to overcome the resistance R and the reactance X (e.m.f. of self-induction) of the circuit are assumed to be 10 volts and 20 volts respectively. Since the current is assumed as constant, IX and IR are also constant. The impedance triangle of the voltage components required to overcome the combined effect of the resistance and the reactance of this circuit is therefore constant. It is shown in five different positions about the semicircle, corresponding to five different load power-factors. The voltage E_s at the sending-end required to maintain 100 volts at the receiving-end is indicated for each of the five positions of the impedance triangle.

Counter-clockwise rotation of the vectors will be considered as positive. This means that when the current is lagging behind the impressed e.m.f., the voltage vector will be in the forward or leading direction from the current vector as indicated by the arrow. When the current leads the impressed voltage, the voltage vector will be in the opposite, or clockwise direction from the current vector. In other words, assuming the vectors all rotating at the same speed about the point O in a counter-clockwise direction, the current vector will be behind the voltage vector when the current is lagging and ahead of it when the current is leading.

The alternating magnetic flux surrounding the conductors, resulting from current flowing through them, generates in them a counter e.m.f. of self-induction. This e.m.f. of self-induction has its maximum value when the current is passing through zero and is therefore in lagging quadrature with the current. On the diagrams an arrow in the line IX, indicates the direction of the e.m.f. of self-induction. It will be seen that since the direction of the current is assumed constant, the e.m.f. of self-induction acts downward in all five impedance diagrams. The sending-end voltage is therefore opposed or favored by this self-induced voltage (see arrows) to a greater or less extent depending upon the power-factor of the load. Thus at lagging loads of high power-factor, the self-induced voltage acts approximately at right angles to the sending-end voltage, and therefore requires a small component of the sending-end voltage to balance or neutralize its effect. As the power-factor of the receiving-end load decreases in the lagging direction (upper quadrant of diagram) the sending-end voltage swings around more nearly in line with the direction of the induced voltage, thus requiring a greater component of the sending-end voltage to counter-balance its effect. At zero power-factor lagging, the direction of the sending-end voltage and that of the induced e.m.f. are practically in opposition (as indicated by the arrows), so that the component of the sending-end voltage required to overcome the induced voltage is a maximum, or nearly as much as the e.m.f. of self-induction. It is interesting to note that at zero lagging power-factor, when the effect of self-induction on line voltage drop reaches a maximum, the sending-end voltage component IR necessary to overcome the resistance of the circuit (now nearly at right angles to the supply voltage), is a minimum. The reverse of these conditions is true for receiving-end loads of power-factors near unity.

Now consider receiving-end loads of leading power-factors, (lower quadrant of diagram). It will be seen that the e.m.f. of self-induction does not now oppose the sending-end voltage (indicated by direction of the arrows) but has a direction more or less parallel to that of the sending-end voltage. At high leading power-factors, the e.m.f. of self-induction has little effect on the sending-end voltage, but as zero leading power-factor is approached these two e.m.f's. more nearly come in phase with each other. At zero power-factor leading, the e.m.f. of self-induction adds almost directly to the sending-end voltage.

It will be seen, therefore, that for receiving-end loads of lagging power-factor, the sending-end voltage is greater than the receiving-end voltage, by an amount necessary to overcome the resistance and self-induction of the circuit. For receiving-end loads of leading power-factor, the sending-end voltage is less than the receiving-end voltage, for the reason that the e.m.f. of self-induction is in such a position as to assist the sending-end voltage.

The following values from Fig. 20 illustrate these conditions:

Power Factor of Receiving End Load	Supply Voltage
0 per cent lagging	120.4
80 per cent lagging	120.4
100 per cent	111.8
80 per cent leading	98.5
0 per cent leading	80.6

The condition of leading power-factor at the receiving-end would be unusual in practice, since the power-factor of receiving-end loads is usually lagging. In cases, however, where condensers are used for voltage or power-factor control, the power-factor at the receiving-end may be leading. If the circuit were without inductance, there could be no rise in voltage at the receiving-end, for in such a case, IX of the diagram would disappear, and the voltage drop would be the same as with direct current. All alternating-current circuits are inductive, and the greater their inductance, the greater will be the voltage drop, or the voltage rise along the circuit.

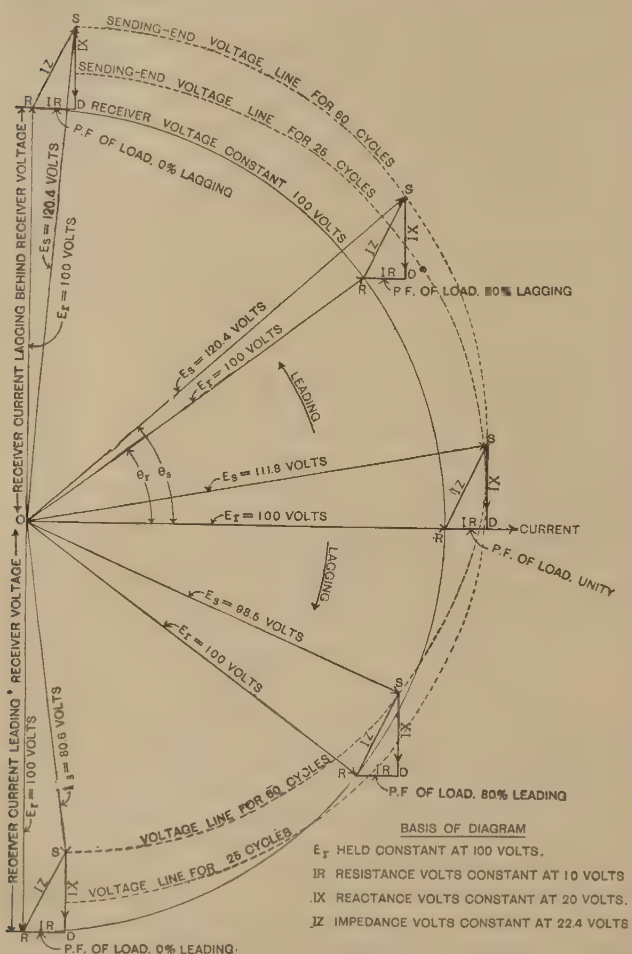


Fig. 20.—Effect of self induction on regulation.

An alternating-current circuit may be looked upon as containing three active e.m.f's. out of phase with each other. In addition to the impressed e.m.f. at the sending-end, there are two e.m.f's. of self-induction, one as the result of the receiving-end current and lagging 90 degrees behind it and the other as the result of the line charging current and lagging 90 degrees behind it. These two combine at an angle, with each other and with the impressed e.m.f. at the sending-end.

CHARGING CURRENT

Conductors of a circuit, being separated by a dielectric (such as air, in overhead circuits, or insulation in cables), form a condenser. When alternating-current flows through such a circuit, current (known as charging current) virtually passes from one conductor through the dielectric to the other conductors, which are at a different potential. This current is in shunt with the circuit, and differs from the current which passes between conductors over the insulators etc. (leakage current) or through the air (corona effect) only in that the charging current leads the voltage by 90 degrees, whereas the leakage current is in phase with the voltage.

For a given spacing of conductors, the charging current increases with the voltage, the frequency and the length of the circuit. For long high-voltage circuits, particularly at 60 cycles per second, the charging current may be as much as the full-load current of the circuit, or more. In some cases of long 60-cycle circuits, where a comparatively small amount of power is to be transmitted, it is necessary to limit the voltage of transmission, in order that the charging current may not be so great as to overload the generators. This charging current, being in leading quadrature with the voltage, represents nearly all reactive power, but it is just as effective in heating the generator windings as if it represented active power. On the other hand, it combines with the receiving-end current at an angle (depending upon the power-factor of the receiver load) in such a manner that the addition of the full-load receiving-end current, in extreme cases, may not greatly increase the sending-end current. In other words (if the charging current is near full-load current) the current at the generator end may not increase much when full load at the receiver end is added, over what it is when no load is taken off at the receiving-end.

Since the e.m.f. of self-induction due to the charging component is proportional to the charging current, its effect upon the voltage regulation of the circuit will also be proportional to the charging current. For a short low-voltage circuit, the charging current is so small that its effect on voltage regulation may be ignored. On the longer circuits, especially long 60-cycle circuits, such as will be considered later, its effect must be given careful consideration.

VARIATION IN CURRENT AND VOLTAGE ALONG THE CIRCUIT

It was explained above and illustrated in Fig. 20 that with a receiving-end load of leading power-factor,

the voltage at the sending-end of the circuit might be less than that at the receiving-end. It was shown that the e.m.f. of self-induction, resulting from the leading current, tends to raise the voltage along the circuit. This boosting effect of the voltage is entirely due to the leading component of the load current.

If, now, it is assumed that the power-factor of the receiving-end load is 100 per cent, there will be no leading component in the load current, and therefore there can be no boosting of the voltage due to the load current. Since, however, all circuits have capacitance, and since the current is alternating, charging current will flow into the line and this being a leading current, the same tendency to raise the voltage along the circuit will take place as is illustrated by Fig. 20.

The upper part of Fig. 21 is intended to give a physical conception of what takes place in an alternating-current circuit. As the load current starts out from the sending-end, and travels along the conductor, it meets with ohmic resistance. This is represented by r in Fig. 21. It also meets with reactance in quadrature to the current. This is represented by jx in the diagram. Superimposed upon this load current is a current flowing from one conductor to the others, in phase with the voltage at that point and representing true power. This current is the result of leakage over insulators and of corona effect between the conductors. It is represented by the letter g in the diagrams. Then there is the charging current in leading quadrature with the voltage. This current does not consume any active power except that necessary to overcome the resistance to its flow.

In Fig. 21 the four linear constants of the alternating-current circuit, r representing the resistance, jx representing the reactance, g representing the leakage and b representing the susceptance, are shown as located, or lumped, at six different points along the circuit. This is as they would appear in an artificial circuit divided into six units. In any actual line, these four constants are distributed quite evenly throughout the length of the circuit.

VOLTAGE AND CURRENT DISTRIBUTION FOR PROBLEM X

The effect of the charging current flowing through the inductance of the circuit gives rise to a very interesting phenomenon. In order to illustrate this effect, the current and voltage distribution for a 60-cycle, 104 kv., three-phase circuit, 300 miles long, is plotted in Fig. 21. This circuit will be referred to as problem X. In such a long 60-cycle circuit, this phenomenon is quite pronounced; so that such a problem serves well as an illustration. The voltage and the current have been determined for points 50 miles apart along the circuit. Values for both the current and the voltage under zero load, also under load conditions have been plotted. The load conditions refer to a receiving-end load of 18,000 kv.a. at 90 per cent power-factor, lagging, 60-cycle three-phase. The voltage is assumed as being held constant 104,000 volts at the receiving-end, for both zero and full-load conditions.

Zero-load Conditions.—Without any load being taken from the circuit, it will be seen that the charging current at the sending-end approaches in value that established when under full load; *i.e.*, 94.75 amp. The charging current drops down to approximately 50 amp. at the middle, and to zero at the receiving-end of the unloaded circuit. The lower full-line curve shows how this current is distributed along the circuit. Starting at zero, at the receiving-end of the circuit, it increases as the sending-end of the circuit is approached, at which point it reaches its maximum value of 87.89 amp. The voltage distribution under zero-load conditions is some-what opposite to that of the current distribution. That is the voltage (104,000 volts at the receiving-end) keeps falling lower until it reached a value of 84,676 at the sending-end. It should be noted that the voltage curve for zero-load condition drops down rapidly as the sending-end is approached. The reason for this is the large charging current flowing through the inductance of the circuit at this end of the circuit. The larger the charging current the greater the resultant boosting of the receiving-end voltage.

Load Conditions.—When 18,000 kv.a. at 90 per cent power-factor lagging is taken from the circuit at the receiving-end, the current at this end goes up to 99.92 amp. As the supply end is approached the current becomes less, reaching its lowest value (approximately 83 amp.) in the middle of the circuit. At the supply end it is 94.75 amp., which is less than it is at the receiver end. Thus the full line representing the current in amperes along the circuit assumes the form of an arc, bending downward in the middle of the circuit. The shape of this current curve is dependent upon the relative values of the leading and lagging components of the current at points along the circuit. The reason that the current is a minimum near the middle of the circuit, is because this is the point where the lagging current of the load and the leading charging current of the circuit balance or neutralize each other, and the power-factor is therefore unity. Starting at the receiving-end, the power-factor is 90 per cent lagging. As the middle of the circuit is approached, the increasing charging current neutralizes an increasing portion of the lagging component of the load current. Near the middle of the circuit, this lagging component is entirely neutralized, and the power-factor rises to unity. Passing the middle and approaching the sending-end there is no more lagging component to be neutralized, and the increasing charging current causes a decreasing leading power-factor which, when the sending-end is reached, becomes 93.42 per cent leading. It will, therefore, be seen that the power-factor as well as the current and voltage varies throughout the length of the circuit.

The voltage distribution under load condition is indicated by the top broken line. In order that the receiving-end voltage may be maintained constant at 104,000 volts, the voltage at the sending-end will vary from 84,676 volts at zero load to 122,370 volts at the assumed load.

THE AUXILIARY OR CIRCUIT CONSTANTS

With the impedance methods considered under the general heading of "Short Transmission Lines" the current was considered as of the same value throughout the circuit, and the voltage drop along the circuit was considered as proportional to the distance. These assumptions, which are permissible in case of short lines, are satisfied by simple trigonometric formulas.

The rigorous solution for circuits of great electrical length accurately takes into account the effect produced by the non-uniform distribution of the current and the voltage throughout the length of the circuit. This effect will hereafter be referred to as the *distribution effect* of the circuit, and may be taken into account through the application of the so-called auxiliary constants of the circuit.

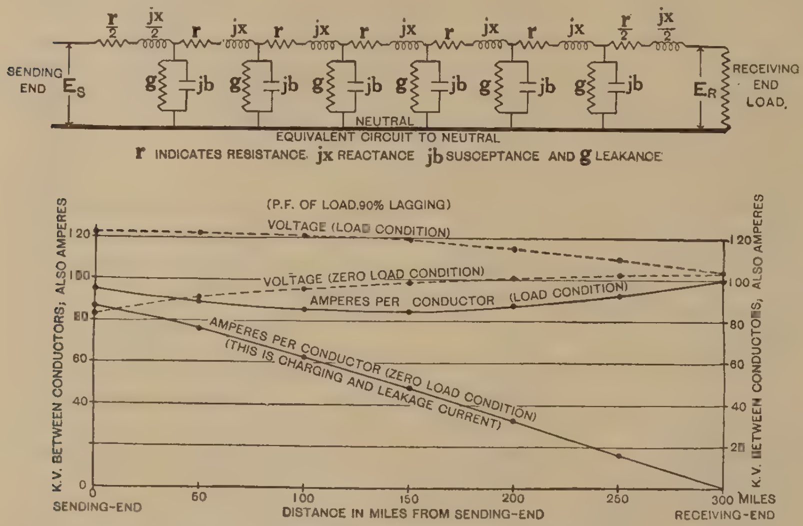


Fig. 21.—Diagams of transmission circuit—problem X.

300 miles long, 104,000 volts delivered, 60 cycle. The upper diagram gives a physical conception of the conditions along the line. The curves show the variation in current and voltage along the circuit.

The auxiliary constants, A, B and C of the circuit are functions of its physical properties, and of the frequency only. They are entirely independent of the voltage or current of the circuit. The various solutions for long transmission circuits are in effect schemes for determining the values of these three auxiliary constants. Mathematically they may be calculated, by hyperbolic functions or by their equivalent convergent series. Graphically they may be obtained to a high degree of accuracy from the accompanying Wilkinson Charts for overhead circuits not exceeding 300 miles in length. They have been calculated, and tabulated in Chapter XXI, for a large number of 60 cycle circuits, and for which circuits they may be obtained directly from the tables. Having determined the values for these three constants for a given circuit, the remainder of the solution is just as simple as for short lines. It is only necessary to apply any desired load conditions to these constants and plot the results by vector diagrams.

DIAGRAM OF THE AUXILIARY CONSTANTS

In Fig. 22 are shown voltage and current diagrams representing the application of the auxiliary constants to the solution of transmission circuit problems. To construct the voltage vector diagram, the two auxiliary constants A and B are required, and to construct the current vector diagram, constants A and C are required.

Since these diagrams are based upon 1 volt and 1 amp. at the receiving end, it is necessary to multiply the values of the auxiliary constants by the volts or the amperes at the receiving end, in order to apply the auxiliary constants to a specific problem. Since the diagrams are shown corresponding to unity power-factor, it will also be necessary to change the position of the impedance and charging-current triangles in case the power-factor differs from unity. This will be explained later.

Constants a_1 and a_2.—Referring to the voltage diagram, Fig. 22, if the line is electrically short the charging current, and consequently its effect upon the voltage regulation is small. In such a case the auxiliary constant a_1 would be unity, and the auxiliary constant a_2 would be zero. In other words, the impedance diagram would (for a power-factor of 100 per cent) be built upon the end of the vector ER, the point O coinciding with the point R. In such a case, the voltage at the sending end, at zero load, would be the same as that at the receiving end. If the circuit contains appreciable capacitance, the e.m.f. of self-induction, resulting from the charging currents which will flow, will result in a lower voltage at zero load at the sending end than at the receiving end of the line, as previously explained. Obviously, the load impedance triangle must be attached to the end of the vector representing the voltage at the sending end of the circuit at a zero load. This is the vector EO of the voltage diagram, Fig. 22. This voltage diagram corresponds to that of a 60-cycle circuit, 300 miles in length. In such a circuit, the effect of the charging current is sufficiently great to cause the shifting of the point O from R (in a short line) to the position shown in Fig. 22. In other words, the voltatge at zero load at the sending end has shifted from ER for circuits of short electrical length, to EO for this long 60-cycle circuit. The auxiliary constants a_1 and a_2, therefore, determine the length and position of the vector representing the sending-end voltage at zero load. Actually, the constant a_2, represents the volts resistance drop due to the charging current, for each volt at the receiving end of the circuit. That is, the line OF equals

approximately one-half the charging current times the resistance R, taking into account, of course, the distributed nature of the circuit. If the circuit is short, it would be sufficiently accurate to assume that the total charging current flows through one-half of the resistance of the circuit. To make this clear, it will be shown later that, for problem X, the resistance per conductor $R = 105$ ohms and the auxiliary constant $C_2 = 0.001463$. Thus, this line will take 0.001463 amp. charging current, at zero load, for each volt maintained at the receiving-end, and since OF = approximately $I_c \times R/2$ we have $OF\ (a_2) = 0.001463 \times {}^{105}\!/\!_2 = 0.0768075$. The exact value of a_2 as calculated rigorously, taking into account the distributed nature of the circuit, is 0.076831. Since the charging current is in leading quadrature with the voltage ER, the resistance drop OF due to the charging current is also at right angles to ER, as in Fig. 22.

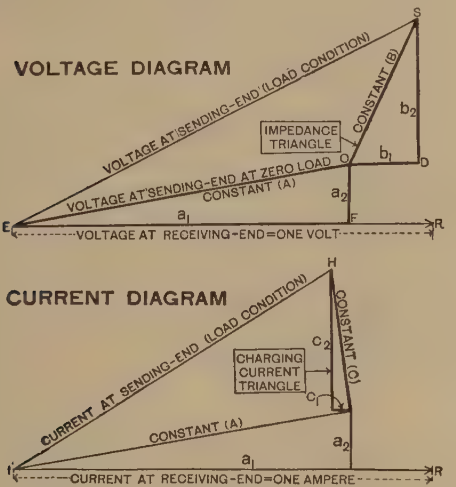


FIG. 22—Diagrammatic representation of auxiliary constants of a transmission circuit.

The vectors are based upon 1 volt and 1 amp. being delivered to the receiving end at unity power-factor. These diagrams correspond to those of a long circuit.

The length of the line FR or $(1 - a_1)$, represents the voltage consumed by the charging current flowing through the inductance of the circuit. This may also be expressed with small error if the circuit is not of great electrical length as $I_c \times X/2$. The reactance per conductor for problem X is 249 ohms. Therefore $FR = 0.001463 \times {}^{249}\!/\!_2 = 0.182143$ and $a_1 = 1.000000 - 0.182143 = 0.817857$. The exact value for a_1 as calculated rigorously, taking into account the distributed nature of the circuit, is 0.810558. The vector FR, representing the voltage consumed by the charging current flowing through the inductance, is naturally in quadrature with the vector OF, representing the voltage consumed by the charging current flowing through the resistance of the circuit.

Constants b_1 *and* b_2 represent respectively the resistance and the reactance in ohms, as modified by the distributed nature of the circuit. The values for these constants, multiplied by the current in amperes at the receiver-end of the circuit, give the IR and IX volts drop consumed respectively by the resistance and the reactance of the circuit. To illustrate this, the values of R and X for problem X are $R = 105$ ohms and $X = 249$ ohms per conductor. The distribution effect of the

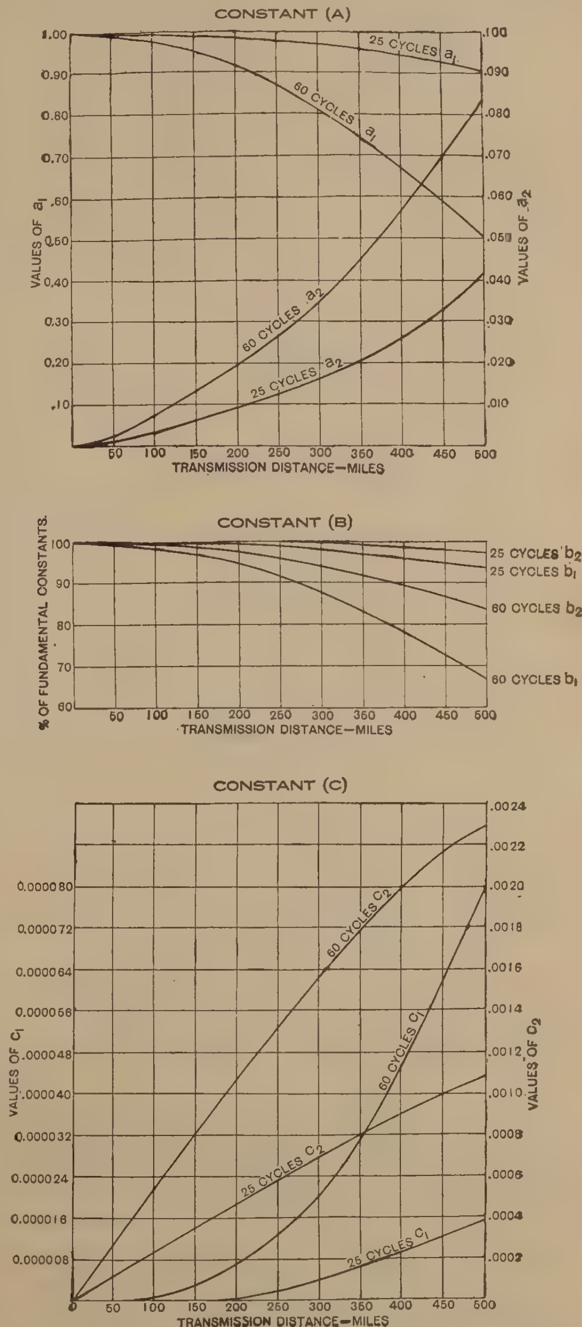


FIG. 23.—Variation of the auxiliary constants for circuits of different lengths.

circuit modifies these linear values of R and X so that their effective values are $b_1 = 91.7486$ and $b_2 = 235.868$ ohms. The impedance triangle, as modified so as to take into exact account the distributed nature of

the circuit, is therefore smaller than it would be if the circuit were without capacitance.

Constants c_1 and c_2 represent respectively conductance and susceptance in mhos as modified by the distributed nature of the circuit. The values for these constants, multiplied by the volts at the receiving-end of the circuit, give the current consumed respectively by the conductance and the susceptance of the circuit. To illustrate, the value of bl for problem X is 0.001563 mho per conductor. The distribution effect of the circuit modifies this fundamental value so that its effective value $c_2 = 0.001463$. The value of c_1 is so small that its effect is negligible for all except very long circuits. For power circuits it will usually be sufficiently

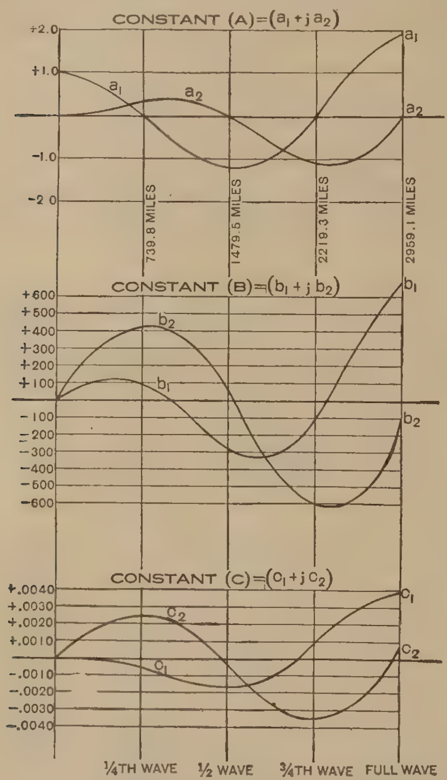


FIG. 24.—Variation of the auxiliary constants.
For a 60 cycle circuit (problem X) up to full wave length.

accurate to neglect c_1. The value c_2 will in such cases represent the charging current at zero load per volt at the receiving-end. Thus c_2, multiplied by the receiving-end voltage, gives the charging current at zero load for the circuit. For problem X, $c_2 = 0.001463$, and this, multiplied by the receiving-end voltage to neutral $60{,}044 = 87.85$ amp. charging current per conductor.

VARIATION IN THE AUXILIARY CONSTANTS

The curves, Fig. 23, will serve to illustrate in a general way how the auxiliary constants vary for both 25- and 60-cycle circuits for lengths up to and including 500 miles. In other words these curves have been plotted from calculated values for these constants for certain circuits.

When the circuit is short, these constants do not vary materially from the linear constants of the circuit, but when the circuit becomes long, they depart rapidly, particularly if the frequency is high.

The auxiliary constants have been calculated for problem X up to and including a full wave length, namely 2,959 miles. Calculations were made only for

AUXILIARY CONSTANTS	WAVE LENGTH OF THE CIRCUIT AND TRANSMISSION DISTANCE—MILES							
	⅛TH	¼	⅜TH	½	⅝TH	¾	⅞TH	FULL
	369.9 MILES	739.8 MILES	1109.7 MILES	1479.5 MILES	1849.4 MILES	2219.3 MILES	2589.2 MILES	2959.1 MILES
a_1	+.716	0	-.789	-1.209	-.942	0	+1.191	+1.922
a_2	+.113	+.323	+.350	0	-.622	-1.104	-.958	0
b_1	+105	+87	-77.5	-276	-330	-122	+292	+670
b_2	+281	+428	+350	+55.5	-330	-605	-560	-135
c_1	-.000075	-.00050	-.0012	-.0016	-.00101	+.00071	+.0028	+.0039
c_2	+.00174	+.00247	+.00169	-.000322	-.00250	-.0035	-.00233	+.00078
(A)	.725 $\angle 8°58'$	.323 $\angle 90°00'$	.863 $\angle 156°05'$	1.209 $\angle 180°00'$	1.129 $\angle 213°26'$	1.104 $\angle 270°00'$	1.528 $\angle 321°11'$	1.922 $\angle 360°00'$
(B)	301.4 $\angle 69°37'$	437 $\angle 78°34'$	358.8 $\angle 102°29'$	282.3 $\angle 168°34'$	469.5 $\angle 225°07'$	619.3 $\angle 258°34'$	635.7 $\angle 297°23'$	682.4 $\angle 348°34'$
(C)	.001743 $\angle 92°29'$	.002527 $\angle 101°26'$	.002075 $\angle 125°21'$	.001633 $\angle 191°26'$	.002715 $\angle 247°59'$	.003582 $\angle 281°26'$	.003677 $\angle 320°15'$	.003947 $\angle 371°26'$

FIG. 25.—Variation of the auxiliary constants.
For problem X up to full wave length.

distances representing each ⅛ wave, that is each 370 miles. The results are tabulated in Fig. 25, and are plotted graphically in Fig. 24. It is interesting to note how these auxiliary constants vary with increasing negative and positive values as the circuit increases in length. A polar diagram is plotted in Fig. 26, indicating the manner in which the auxiliary constant A and its rectangular co-ordinates vary. Although these extreme variations are instructive and interesting, they are not encountered in power transmission circuits, although they will be in long distance telephone practice.

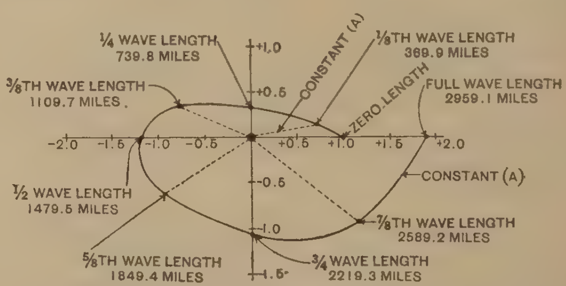


FIG. 26.—Polar diagram.
Showing the variation of the auxiliary constant A for problem X, up to full wave length.

COMPARISON OF SHORT AND LONG LINE DIAGRAMS

The graphical construction for short lines represented typically by the Mershon Chart is so generally known and understood that a similar construction modified to take into accurate account the distribution effect of long lines will readily be followed. Both the short and the long line diagrams are reproduced in Fig. 26a. From these diagrams it will be seen how the three auxiliary constants correct or modify the short line diagram adapting it to long line problems. The two mathematical, three graphical and one tabular method of obtaining the auxiliary constants are indicated at the bottom of this figure. Having determined

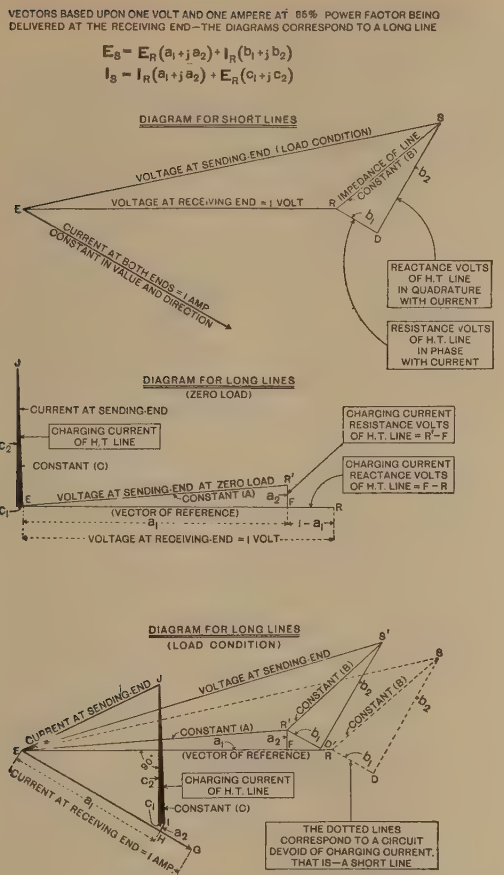


FIG. 26a.—How the auxillary constants modify short line diagrams adapting them to long line problems.

HOW THE AUXILIARY CONSTANTS MAY BE OBTAINED

$(A) = (a_1 + ja_2) = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40.320} + \text{etc.}\right.$ (by convergent series—see Chart XI)

$= \cosh\theta$ (by real hyperbolic functions—see Chart XVI)

$= \frac{\sinh\ \theta/\theta}{\tanh\ \theta/\theta}$ (graphical—see Kennelly Correcting Factor Charts XVIII–XIX–XX–XXI)

$= \cosh\theta$ (graphical—see Kennelly's Chart Atlas, Harvard Press)

$= \cosh\theta$ (all graphical from Wilkinson's Chart "A"—see Chart V)

= for 60 cycle lines from Tables at back of book

$(B) = (b_1 + jb_2) = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5,040} + \frac{Y^4Z^4}{362,880} + \text{etc.}\right]$ (by convergent series—see Chart XI)

$= \sqrt{\frac{Z}{Y}}\sinh\theta$ (by real hyperbolic functions—see Chart XVI)

$= Z\frac{\sinh\ \theta}{\theta}$ (graphical—see Kennelly's Correcting Factor Charts XVIII–XIX)

$= \sqrt{\frac{Z}{Y}}\sinh\theta$ (graphical—see Kennelly's Chart Atlas, Harvard Press)

$= \sqrt{\frac{Z}{Y}}\sinh\theta$ (all graphical from Wilkinson's Chart "B"—see Chart VI)

= for 60 cycle lines from tables at back of book

$(C) = (c_1 + jc_2) = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5,040} + \frac{Y^4Z^4}{362,880} + \text{etc.}\right]$ (by convergent series—see Chart XI)

$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta$ (by real hyperbolic functions—see Chart XVI)

$= Y\frac{\sinh\ \theta}{\theta}$ (graphical—see Kennelly's Correcting Factor Charts XVIII–XIX)

$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta$ (graphical—see Kennelly's Chart Atlas, Harvard Press)

$= \frac{1}{\sqrt{\frac{Z}{Y}}}\sinh\theta = \sqrt{\frac{Y}{Z}}\sinh\theta$ (all graphical from Wilkinson's Chart "C"—see Chart VII)

= for 60 cycle lines from tables at back of book where $\theta = \sqrt{ZY}$

by any of the six methods referred to, the value for the auxiliary constants corresponding to a given circuit, the remainder of the solution for any receiving end current or voltage is readily performed graphically.

Referring to the formulas at the top of Fig. 26a, $E_r(a_1 + ja_2)$ is that part of E_s which would have to be impressed at the sending end if $I_r = o$, or the line was freed at the receiving end with E_r steadily maintained there. It may be called the "free" component of E_s.* Again $I_r\ (b_1 + jb_2)$ is that other part of E_s which would have to be impressed at the sending end, if $E_r = o$, or the line was short-circuited at the receiving end, with I_r steadily maintained there. It may be called the "short" component of E_s.

Similarly, the term $I_r\ (a_1 + ja_2)$ is the component of I_s necessary to maintain I_r at the receiving end without any voltage there ($E_r = o$); while $E_r\ (c_1 + jc_2)$ is the component of I_s necessary to maintain E_r at the receiving end without any current there ($I_r = o$). The reason that c_1 is likely to be negative in ordinary power lines is because the complex hyperbolic angle of any good power transmission line has a large slope, being usually near 88 degrees. The sinh of such an angle, within the range of line lengths and sizes of θ ordinarily present, is also near 90 degrees in slope. The surge impedance $Z_o = \sqrt{\frac{Z}{Y}}$ of such a line is not far from being reactanceless; but it usually develops a small negative or condensive slope. This means that the surge admittance $Y_o = \frac{1}{Z_o}$ usually develops a small positive slope. Consequently, C or the product $E_r\ (c_1 + jc_2)$ usually slightly exceeds 90 degrees in slope; or c_1 becomes a small negative rectilinear component.

THE WILKINSON CHARTS

Mr. T. A. Wilkinson has prepared charts from which the auxiliary constants may be read directly, thus abridging a great amount of tedious mathematical calculation. These charts, are plotted for circuits of lengths up to and including 300 miles.†

The reading of these charts is simplified by reason of the fact that all three charts are somewhat similar. In following any of them, the start is made from the intersection of the short arc representing length of cir-

* See paper by Houston and Kennelly on "Resonance in A.-C. Lines" in *Transactions*, A. I. E. E., April, 1895.

† Similar Charts by Mr. Wilkinson were published in *Electrical World*, Mar. 16, 1918.

CHART V—WILKINSON CHART A

(FOR DETERMINING AUXILIARY CONSTANTS—ZERO LOAD VOLTAGE)

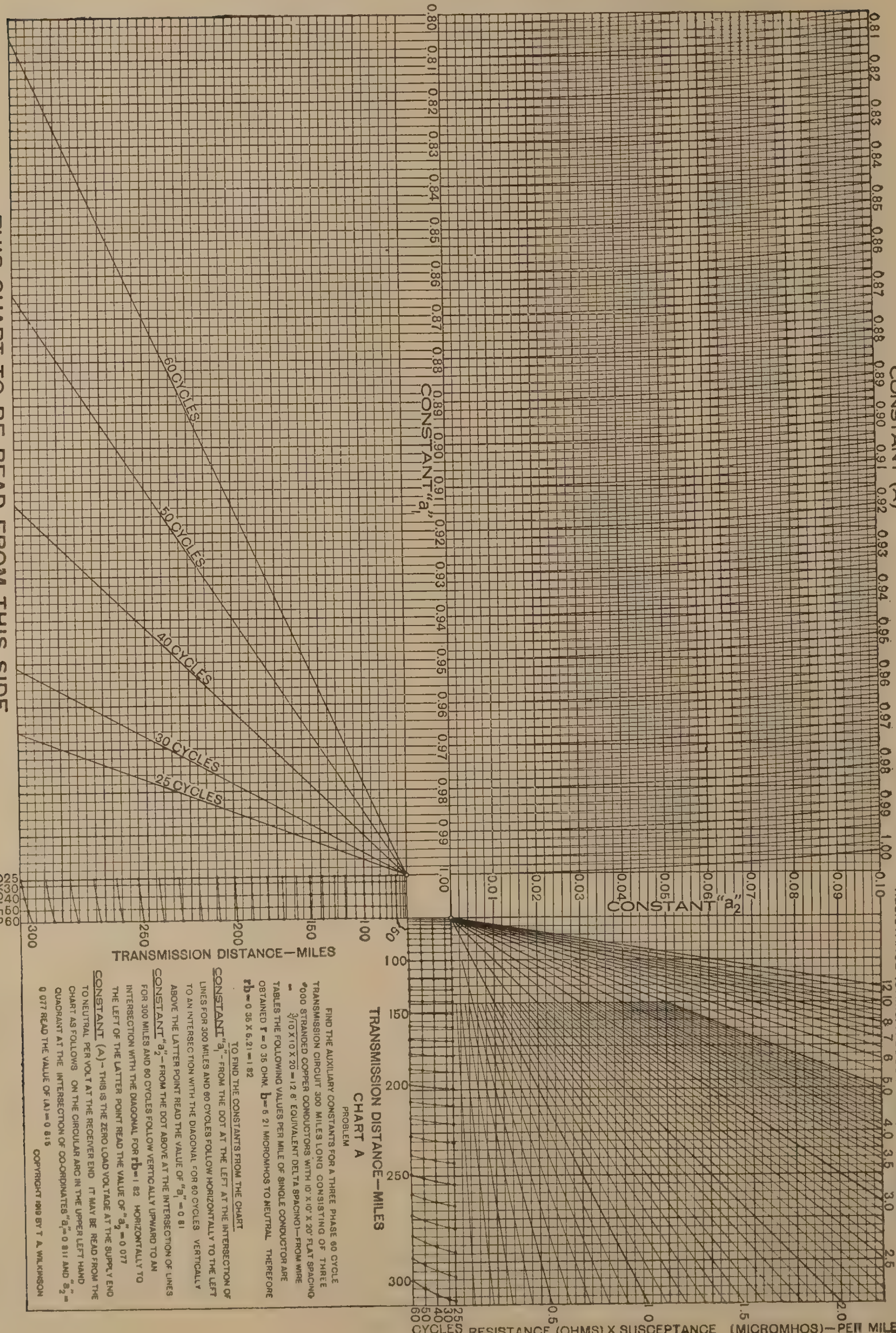


CHART VI—WILKINSON CHART B

(FOR DETERMINING AUXILIARY CONSTANTS—LINE IMPEDANCE)

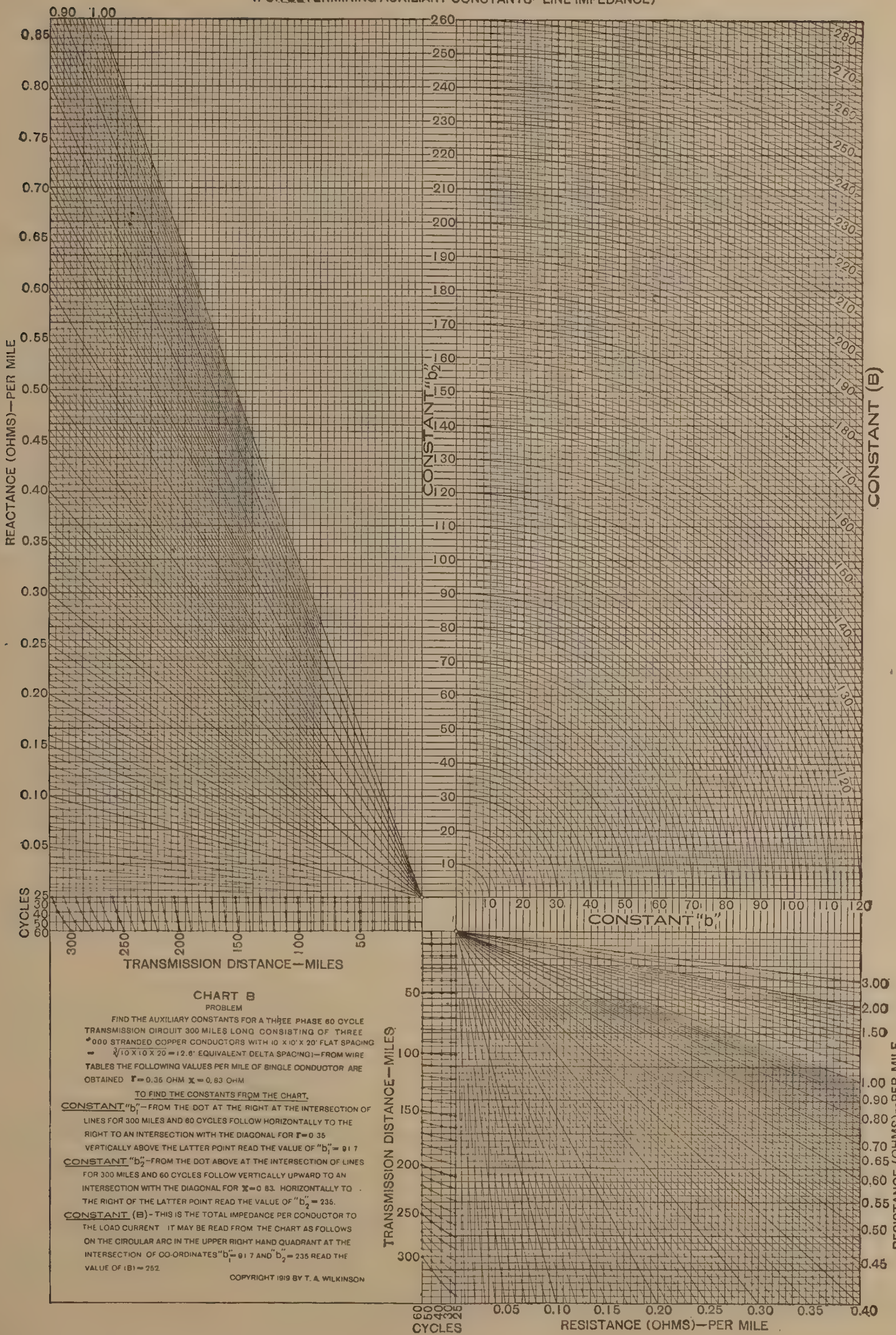
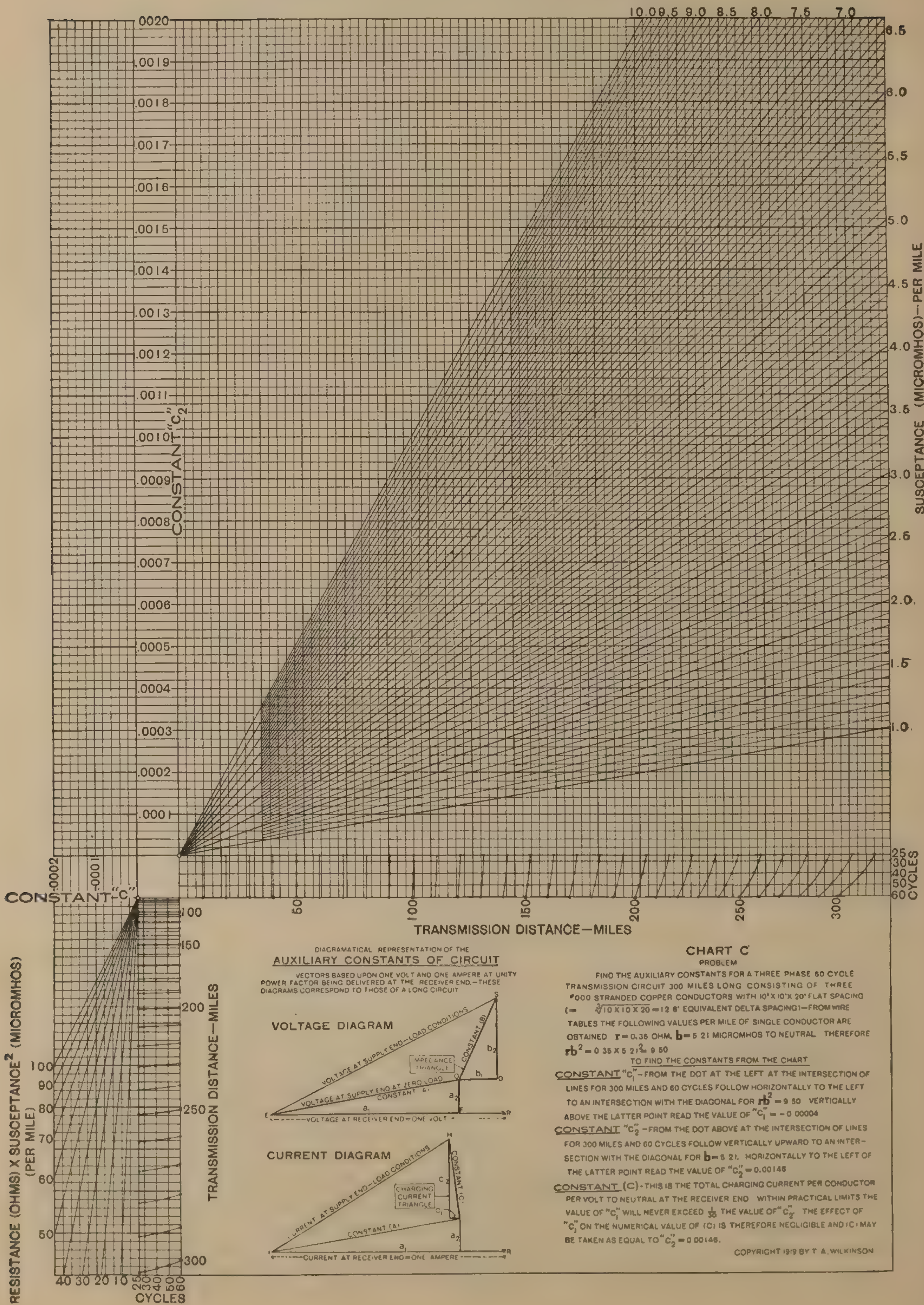


CHART VII—WILKINSON CHART C

(FOR DETERMINING AUXILIARY CONSTANTS—CHARGING CURRENT)



cuit and the straight line representing the frequency. From this intersection a straight line is followed to a diagonal line and thence at right angles to the constant required. Thus in a few minutes the auxiliary constants of the circuit may be obtained directly from the chart, whereas, by a mathematical solution from 15 min. to 1 hr. might be consumed in obtaining them. It is not, however, the time saved in obtaining these constants which is most important. The greatest advantage in this graphical solution for the auxiliary constants is that it not only abridges the use of a form of mathematics which the average engineer is inefficient in using, but it tends to prevent serious mistakes being made. In calculating these auxiliary constants by either convergent series or hyperbolic methods, an incorrect algebraic sign assigned to a number may cause a very serious error. Errors of magnitude are less likely to occur when using a comparatively simple graphical solution.

In order to determine the accuracy obtainable by a complete graphical solution, using the Wilkinson Charts for obtaining the auxiliary constants and vector diagrams for the remainder of the solutions, 48 problems were solved both graphically and mathematically. These problems consisted of circuits varying between 20 and 300 miles in length, and voltages varying between 10,000 and 200,000 volts. Twenty-four problems were for 25-cycle and the same number for 60-cycle circuits. The maximum error in supply-end voltage by the graphical solution employing a four times magnifying glass was one-fourth of 1 per cent. A tabulation of the results as determined by various methods for these circuits will follow later.

APPLICATION OF TABLES

The application of the table to long transmission lines follows, in general, the same plan as for short lines, published as Chart II, with such modifications as are produced by the effects of distributed capacitance and reactance. The procedure best suited for long transmission lines is shown in Chart VIII.

GRAPHICAL SOLUTION OF PROBLEM X

Problem X.—Length of circuit 300 miles, conductors three No. 000 stranded copper spaced 10 by 10 by 20 ft. (equivalent delta 12.6 ft.). Temperature taken as 25°C. Load conditions at receiving end 18,000 kv.a. (16,200 kw. at 90 per cent power-factor lagging) 104,000 volts, three-phase, 60 cycles.

$$E_{rn} = \frac{104{,}000}{1.732} = 60{,}046 \text{ volts.}$$

$$I_r = \frac{6{,}000 \times 1{,}000}{60{,}046} = 99.92 \textit{ amp.}$$

From tables the following linear constants per mile are determined.

r = 0.35 ohm (an old table)
x = 0.83 ohm (an old table by interpolation)
b = 5.21 micromhos (an old table by interpolation)
g = (in this case taken as zero)

therefore,

$rb = 0.35 \times 5.21 = 1.82$

and

$rb^2 = 0.35 \times 5.21^2 = 9.50$

Chart VIII.—Application of Tables to Long Transmission Lines

(Effect of Distributed Capacitance Taken into Account) Overhead Bare Conductors

Starting with the kv.a., voltage and power-factor at the receiving end known.

Quick Estimating Tables

From the quick estimating table corresponding to the voltage to be delivered, determine the size of the conductors corresponding to the permissible transmission loss.

Corona Limitation

If the transmission is at 30,000 volts, or higher, the corona table should be consulted to avoid the employment of conductors having diameters so small as to result in excessive corona loss.

Resistance—Tables V and VI

From one of these tables obtain the resistance per unit length of single conductor corresponding to the maximum operating temperature—calculate the total resistance for one conductor of the circuit.

Reactance—Tables IX to XII

From one of these tables obtain the reactance per unit length of single conductor. Calculate the total reactance for one conductor of the circuit. If the reactance is excessive (20 to 30 per cent reactance volts will in many cases be considered excessive) consult Tables XIII to XVI. Having decided upon the maximum permissible reactance the corresponding resistance may be found by dividing this reactance by the ratio value in Tables XIII to XVI. When the reactance is excessive, it may be reduced by installing two or more circuits and connecting them in parallel, or by the employment of three conductor cables. Using larger conductors will not materially reduce the reactance. The substitution of a higher transmission voltage, with its correspondingly less current, will also result in less reactance.

Capacitance Susceptance—Tables XIX to XXII

From one of these tables obtain the capacitance susceptance to neutral, per unit length of single conductor. Calculate the total susceptance for one conductor of the circuit to neutral.

Graphical Solution

From the Wilkinson Charts obtain the auxiliary constants. Applying these auxiliary constants to the load conditions of the problems, make a complete graphical solution as explained in the text. Vector diagrams of the voltage and the current at both ends of the circuit are then constructed, from which the complete performance can be readily obtained graphically.

Mathematical Solution

As a precaution against errors in those cases where accuracy is essential, the result obtained graphically should be checked by the convergent series or the hyperbolic method.

The auxiliary constant of the above circuits are now taken directly from the Wilkinson Charts. This problem is stated on the Wilkinson Chart. Following

the directions printed on the charts, we obtain for this circuit the following values for the auxiliary constants.

$$a_1 = 0.81 \quad b_1 = 91.7 \quad c_1 = 0.00004$$
$$a_2 = 0.077 \quad b_2 = 235 \quad c_2 = 0.00146$$

From this point on, the solution is made graphically as indicated in Fig. 27. It should be noted here that the auxiliary constants obtained from the Wilkinson Charts are practically the same as those stated at the top of Fig. 27, which values were calculated rigorously by convergent series. We will employ the rigorous values in plotting the diagram so that the values on the diagram will agree with the values of voltage and current calculated rigorously which will appear in a later section. The j terms preceding some of the numerical values in Fig. 27 apply to the mathematical treatment, and have no significance in connection with the graphical solution.

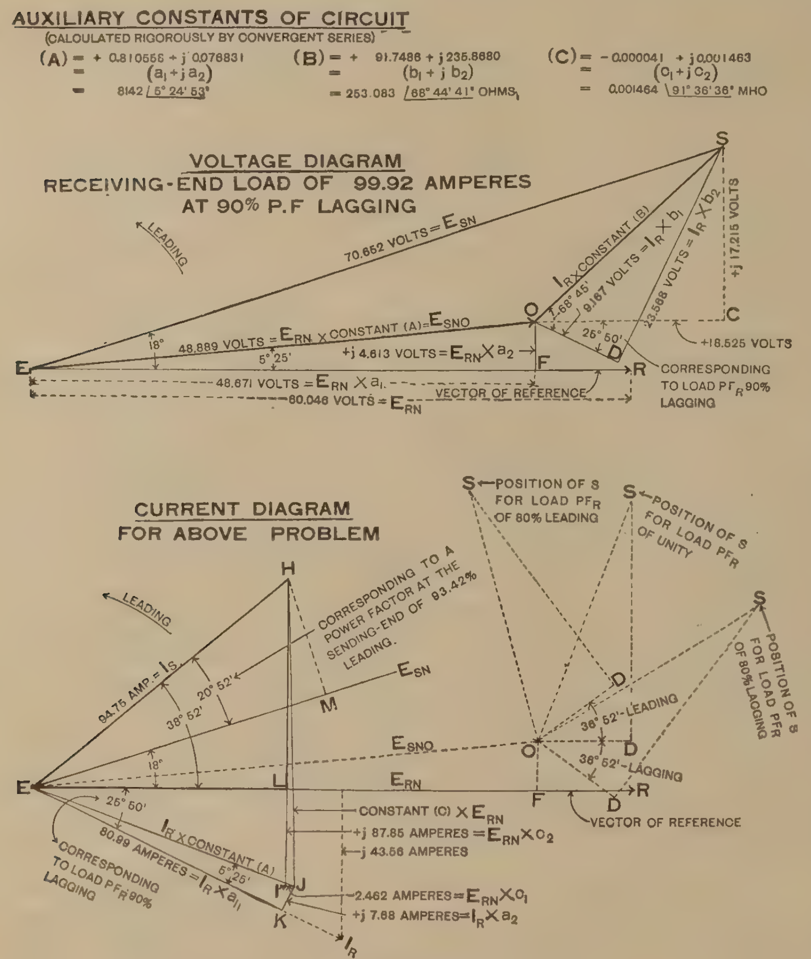


FIG. 27.—Graphic solution of problem X.

VOLTAGE DIAGRAM

The vector ER, representing the constant voltage at the receiving-end (for all loads) is first laid off to some convenient scale. Along this vector, starting from E, lay off a distance equal to the receiving-end voltage multiplied by the constant a_1 ($60{,}046 \times 0.810558 = 48{,}671$ volts). This is EF of Fig. 27. From F lay off vertically (to the same scale) the line FO equal to the receiving-end voltage multiplied by the constant a_2 ($60{,}046 \times 0.076831 = 4{,}613$ volts). Connect the points O and E by a line. This line EO represents the voltage at the sending end at zero load. This voltage vector may, if desired, be located by polar co-ordinates in place of rectangular co-ordinates. If it is desired to work with polar co-ordinates lay off the line EO at an angle of 5° 25′ in the forward direction from the receiving-end voltage vector ER. (For the graphical solution it is not necessary to take account of seconds in angles.) The length of the vector EO will be found by multiplying the constant A by the receiving-end voltage ($0.8142 \times 60{,}044 = 48{,}889$ volts).

Having located the point O, the impedance triangle is built upon it in the following manner. Since the power-factor of the load is 90 per cent lagging, determine from a table of cosines what the angle is whose cosine is 0.9. This is found (from Table K) to be 25°, 50′. Lay off the line OD at an angle with the vector of reference ER of 25° 50′ in the lagging direction. The length of OD will be determined by multiplying the current in amperes per conductor by the auxiliary constant b_1 ($99.92 \times 91.7486 = 9{,}167$ volts). This represents the resistance drop per conductor. From the point D thus found draw a line DS at right angle with OD. This line DS represents the reactance volts per conductor; its length is found by multiplying the current in amperes per conductor by the auxiliary constant b_2 ($99.92 \times 235.868 = 23{,}568$ volts). Connect the point S with E, the length of which represents the voltage (70,652 volts) at the sending end for the load conditions assumed. The vector OS could be laid off by the use of polar ordinates as follows. The polar co-ordinate OS is stated as $B = 253.08 /68° 44′ 41″$ per ampere at the receiving end. 68° 45′ − 25° 50′ = 42° 55′ the angle COS. The vector OS is therefore laid off at an angle of 42° 55′ with the vector of reference ER or OC. The length of the vector OS is $253.08 \times 99.92 = 25{,}288$ volts. The triangle OCS indicated by broken lines is not required for the graphical solution but is calculated in the case of one form of mathematical solution which will follow.

Had the power-factor of the receiving-end load been unity in place of 90 per cent lagging, the impedance triangle would have been plotted vertically, that is OD would have been drawn parallel with ER. In the bottom diagram (representing the graphical solution for current) the position of the impedance diagram is indicated by broken lines corresponding to loads of three different power-factors.

CURRENT DIAGRAM

Lay off the vector ER representing the direction of the receiving-end voltage. Since the power-factor of the current at the receiving-end is 90 per cent lagging, lay off the line EK at an angle of 25° 50′ from the vector of reference ER and in the lagging direction. To some suitable scale for the current values, measure off EK equal to the current at the receiving-end multiplied by the constant a_1 (99.92 × 0.810558 = 80.96 amp.). From the point K thus located lay off KJ at right angles to EK and equal in length to the receiving-end current multiplied by constant a_2 (99.92 × 0.076831 = 7.68). This fixes the point J upon which the charging-current diagram will be built. The point J may also be located by the use of polar co-ordinates if desired. Thus EJ = 25° 51′ − 5° 25′ = 20° 25′ in a lagging direction from the vector of reference ER. The length of EJ = 99.92 × 0.8142 = 81.35 amp.

Now draw the line IJ parallel to the vector of reference ER. The length of IJ is found by multiplying the receiving-end voltage by the constant c_1 (60,046 × 0.000041 = 2.462 amp.). Since c_1 is a negative value the line JI turns to the left, the negative direction. From the point I thus located draw the vertical line IH equal to the receiving-end voltage multiplied by the constant c_2 (60,046 × 0.001463 = 87.85 amp.). This locates the point H ,which is now connected by a line with E. The vector EH represents the sending-end current = 94.75 amp.

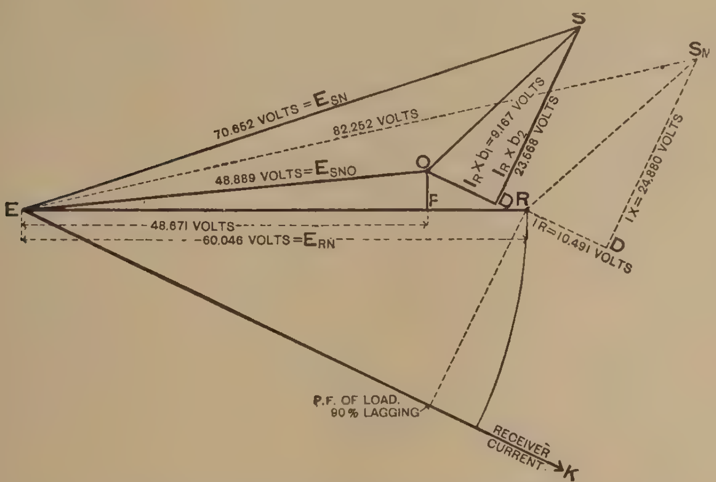


FIG. 28.—Comparison of graphic solutions for problem X.

The full line diagram takes into account the effect of distributed capacitance. The dotted line diagram (impedance method) neglects the effect capacitance.

The vector representing the sending-end voltage having been located in the voltage diagrams at an angle of 18° in the leading direction, may be plotted in the current diagram. The angle between the current and the voltage at the sending end may be measured and will be found to be 20° 52′ for this problem, corresponding to a power-factor of 93.42 per cent. Since the current vector leads the voltage vector the power-factor at the sending end is leading.

It has been shown above how to determine graphically the voltage, current, phase angle and consequently the power-factor at the sending end of the circuit. These values thus determine the true power input at the sending end. This true power may also be determined graphically as follows.

The component of the current at the sending end which is in phase with the voltage at the sending end may be scaled off on the current diagram in Fig. 27 as follows. On the diagram the vector EH represents the direction and value of the current at the sending-end and the vector E_{sn} the direction of the voltage at the sending-end. At right angles to the vector E_{sn} draw the line HM passing through the point H (the end of the current vector). To the same scale that EH is drawn measure off along the vector E_{sn} the distance from E to M. This will be the amperes in phase with the voltage at the sending end. This value multiplied by the voltage at the sending end, will give the true power at the sending end.

COMPARATIVE GRAPHICAL SOLUTIONS

In Fig. 28 are shown two graphical solutions for problem X. The full-line diagram is correct, taking into account the effect of the distributed capacitance. The broken-line diagram (the Mershon Chart for short lines) does not take into account any capacitance effect. Of course the Mershon Chart would not be employed in the solution of long lines, such as given in problem X. It is shown here simply to illustrate wherein these two graphical methods differ. The following remarks regarding the Mershon Chart will apply equally to any of the other impedance methods, since they take no account of capacitance effect.

The Mershon Chart is built upon the receiving-end current as a vector of reference, whereas the full-line chart is built up from the receiving-end voltage as a vector of reference. The impedance triangle in the full-line chart is built upon the vector representing the zero-load voltage at the sending end, whereas the broken-line impedance triangle is built upon the vector representing the voltage at the receiving end. Herein lies the principle source of error in the application of the Mershon Chart to circuits of considerable capacitance. The correct position for the impedance triangle is on the end of the vector representing the sending-end voltage at zero load.

The impedance triangle is smaller in the full diagram than in the Mershon diagram. Herein lies another source of error in the application of the Mershon Chart to circuits of considerable capacitance. The full-line impedance triangle takes into account the distributed effect, or change in current along the circuit, whereas the Mershon Chart is based upon the current being of the same value throughout the length of the circuit.

The actual sending-end voltage is 70,652, as indicated on the full-line chart, whereas by the broken line or Mershon Chart method it would be incorrectly given as 82,252 volts.

VOLTAGE AND CURRENT AT INTERMEDIATE POINTS ALONG THE CIRCUIT

Thus far we have considered the electrical condition at the two ends of a transmission circuit only. Occasionally it may be desired to determine the voltage or the current at a point, or at various points along the circuit. In Fig. 21, graphs of the voltage and of the current are shown for points between the terminals of a circuit corresponding to the condition of zero load, and also of rated load. The graphs were plotted by determining graphically the voltage and the current for points at 50-mile intervals along this 300-mile circuit, as follows:

To determine the conditions 250 miles from the sending end, (50 miles from the receiving end) the three auxiliary constants were obtained from the Wilkinson Charts corresponding to a circuit 50 miles long. In other words, it was assumed that the circuit was only 50 miles long. By multiplying these auxiliary constants by the known voltage and current at the receiving end of the circuit, voltage and current diagrams were constructed as in Fig. 27 and on these, the corresponding values of voltage and current at the sending end of the 50-mile section were scaled off. This gives the conditions, for the load assumed, at a point 250 miles from the sending-end. In a similar manner the voltage and current at this point, corresponding to zero load at the receiving-end, may be obtained. A similar procedure will determine the electrical conditions for a point 100 miles from the receiving end (200 miles from the sending end). The auxiliary constants will this time be read from the charts, corresponding to a 100-mile circuit, but the same receiving-end conditions will be used, as before. The electrical condition for any intermediate points along any smooth line, may thus be readily determined.

CHAPTER IX

PERFORMANCE OF LONG TRANSMISSION LINES BY CONVERGENT SERIES

The approximate electrical performance of overhead circuits having a length not exceeding 300 miles, may readily be determined by the use of the Wilkinson Charts for determining the values of the auxiliary constants, supplemented by vector diagrams representing the current and voltages of the circuits. In important cases, as a final check upon the values obtained by the simple graphical solution, a mathematical solution yielding rigorous results should be made. If the circuit is more than 300 miles long, a mathematical solution yielding rigorous values will be required for determining the correct values of at least the auxiliary constants.

FORMS OF RIGOROUS SOLUTIONS

The most direct method for determining mathematically the exact performance of circuits of great electrical length is by the employment of hyperbolic functions, and the fundamental equations are usually expressed in such terms. Many engineers have a general aversion to the use of mathematical expressions employing hyperbolic functions. One reason for this is that the older engineers attended college before the hyperbolic theory as applied to transmission circuits had been developed, and tables of such functions were not at that time available.

In 1893 Dr. A. E. Kennelly introduced vector arithmetic into alternating-current computation for the first time.* Although real hyperbolic functions had well recognized uses in applied science, it was in 1894† that he, for the first time, suggested and illustrated the application of vector hyperbolic functions to the determinations of the electrical performance of transmission circuits. Since that time Dr. Kennelly has been a most persistent advocate of the employment of these functions in electrical engineering problems. To advance their use, he has calculated and published numerous tables and charts of such functions. Such tables were, until recently, incomplete and the result was that it was necessary, in using these tables, to interpolate values, thus introducing complications and inaccuracies into the calculations.

Tables of hyperbolic functions and charts are now sufficiently extensive and complete for accurate work. The universities quite generaly are encouraging instruction of students in the hyperbolic theory. It is therefore to be expected that, in the future, the employment of hyperbolic functions for the solution of long transmission lines will come into general use.

The fundamental hyperbolic equations expressing the electrical behavior of transmission circuits may be expressed in the form of convergent series and, in such form have, in some cases, certain advantages over the hyperbolic form. The convergent series form of solution does not require the employment of tables or charts of hyperbolic functions, whereas hyperbolic forms of solutions do require such tables or charts. If, therefore, such tables or charts are not available, hyperbolic solutions cannot be employed.

While the amount of arithmetical work involved is considerable, any degree of accuracy may readily be obtained by the convergent series solution by working out the terms for the auxiliary constants until they become too small to have any effect upon the results. This can also be done with hyperbolic functions, but exact interpolation of such functions from tabular values may be considered more difficult than the working out of an extra term or two in the convergent series form of solution. The above remarks apply to cases where an unusual degree of accuracy is required. Later will be included a tabulation of the performance of 64 different electrical circuits, as determined by a rigorous, and also by eight different approximate methods of calculation. As the rigorous values are taken as 100 per cent correct, in determining the per cent error by the approximate methods, it was important that the so called "rigorous" values be exact. To make them so, it was found convenient to employ the convergent series form of solution for these particular problems, covering circuits up to 500 miles long and potentials up to 200,000 volts. For the calculation of the performance of practical power transmission tables of hyperbolic functions are now sufficiently complete to yield results well within the errors due to variation in the assumed linear constants of the circuits from their actual values.

The employment of convergent series requires a working knowledge of complex quantities only, whereas the employment of hyperbolic functions in addition leads into hyperbolic trigonometry. As literature pertaining to the hyperbolic theory becomes more generally available, and as the younger engineers take up active engineering work, the hyperbolic theory will become more generally used.

For the purpose of providing a choice of rigorous methods both convergent series and two forms of

* Impedance, *Transactions*, A. I. E. E., Vol. X, p. 175.

† The Fall of Pressure in Long-distance Alternating-Current Conductors, *Electrical World*, Vol. XXIII, No. 1, p. 17, January, 1894.

hyperbolic solutions are given. The numerical values employed in these solutions have been carried to what may appear as an unnecessary degree of precision. The reason for this is to demonstrate the fact that all of these rigorous solutions yield the same results. For practical problems less accuracy would be required thus reducing the amount of arithmetical work.

Before taking up the rigorous solutions, it has been thought desirable to review the rules regarding the use of complex quantities and vector operations.

COMPLEX QUANTITIES

The calculation of the auxiliary constants of the circuit by convergent series, and the further calculation of the electrical performance of the circuit, involve the use of complex numbers, that is, numbers containing j terms. Thus $A = a_1 + ja_2$ is a complex quantity. To the beginner, expressions containing j terms may seem difficult to understand. It cannot be made too emphatic that the rules governing the use of such terms are so simple (embodying only the simple rules of algebra) that the beginner will shortly be surprised with the ease at which complex quantities are handled.

j Terms.—In complex notation $Z = X + jY$, the prefix j indicates that the value Y is measured along the axis perpendicular to that of X, or what is called the imaginary axis. There need be no significance attached to the symbol j other than that of a mere distinguishing mark, to designate a distance above or below the reference axis in the vector diagram. However, great use is made of a further assigned significance. It has a numerical significance in the form of $j = \sqrt{-1}$ which enables all formal algebraic operations, multiplication, addition, extraction of roots, etc. incident to computation involving complex quantities, to be carried out rigorously. This numerical designation for j does not prevent its use as a designating symbol for the vertical direction in the vector diagram.*

PLANE VECTORS

Alternating voltages and currents which vary according to the sine or cosine law, may be represented graphically by directed straight lines, called plane vectors. The length of the vector represents the effective value of the alternating quantity, while the position of the vector with respect to a selected reference vector, base or axis, gives the phase displacement. The line OP, of Fig. 29, represents a plane vector inclined at an angle of 33° 41′ with the base OS (the axis of reference). The length of the line OP is a measure, to some assumed scale, of the effective value of the voltage or current, while the angle SOP gives the phase displacement.

Counter-clockwise rotation is considered positive. Thus, in Fig. 29, if the line OS represents the instantaneous direction of the current and the line OP that of the voltage at the same instant, the current is represented as lagging behind the voltage by the angle 33° 41′. By means of vectors the relative phase position and value of either currents or e.m.f.'s. can be represented in the same manner as forces in mechanics.

The position of P, with respect to O, is usually defined in terms of rectangular or polar co-ordinates. In rectangular co-ordinates there are two fixed mutually perpendicular axes, $-XOX$ and $-YOY$ (Fig. 31) in the plane of reference. The former, $-XOX$, is called the real axis, or axis of real quantities. The latter, $-YOY$, is called the imaginary axis, or axis of imaginary quantities. The qualifying adjective "imaginary" does not mean that there is anything indeterminate or fictitious about this axis. The perpendicular projections of P-1 (Fig. 31) on the X and Y axes are respectively the real component X, and the imaginary component Y.

The magnitude and sign of the rectangular components X and Y completely determine the position of the vector OP. Positive is indicated to right and upward, negative to the left and downward as indicated in Fig. 30. Thus, if X and Y are both positive, OP lies in the first quadrant. If X and Y are both negative, OP lies in the third quadrant. If X is $-$ and Y is $+$, OP lies in the second quadrant. If X is $+$ and Y is $-$, OP lies in the fourth quadrant. Any plane vector may be completely specified by its real and imaginary components X and Y. Thus, beneath Fig. 31, is a table in which the point P is located in the plane by co-ordinates for all quadrants.

From Fig. 30 it is evident that, mathematically, the quadrature numbers are just as real as the others. The quadrature numbers represent the vertical, and the ordinary numbers the horizontal directions.

VECTOR OPERATIONS

In general, in the handling of complex numbers involving j terms, the simple rules of algebra are followed. In Fig. 32 two vector quantities are shown. Vector A has a magnitude of 5 units and is inclined in the positive or leading direction at an angle of 36° 52′ with the horizontal reference vector, and vector B has a magnitude of 4.47 units, and is inclined in the positive or leading direction at an angle of 63° 26′ with the reference vector. These vector quantities are expressed in rectangular co-ordinate as $A = +4 + j3$, $B = +2 + j4$ or in polar co-ordinates as $A = 5\underline{/36° \ 52'}$, $B = 4.47 \underline{/63° \ 26'}$. The prefix j simply means that the number following it is measured along the vertical or Y axis. The absolute value of A would be $\sqrt{(4)^2 + (3)^2} = 5$ and of $B = \sqrt{(2)^2 + (4)^2} = 4.47$. The absolute value of a complex number is called its "size;" while the angle is called its "slope."

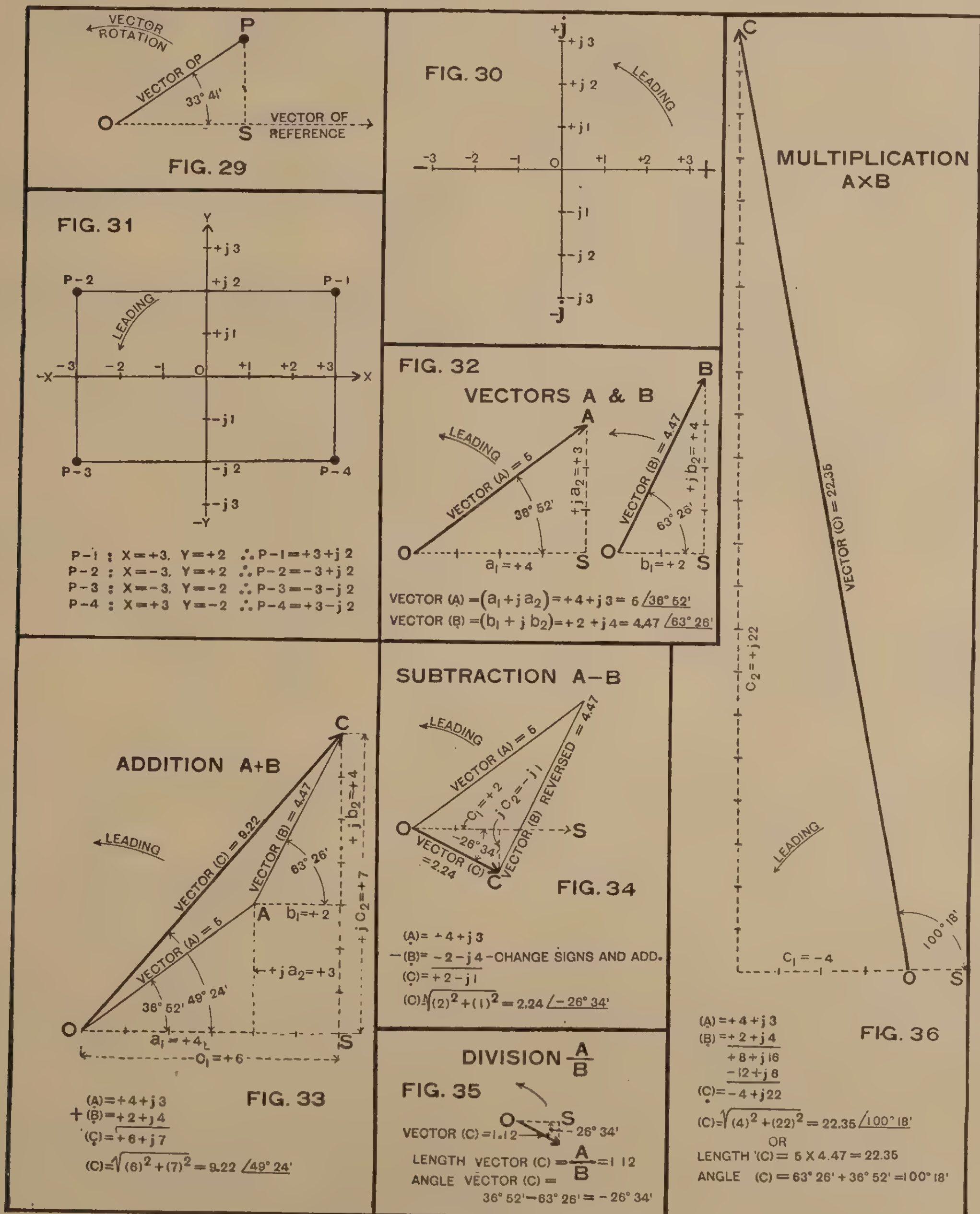
In order to illustrate the handling of complex quantities, the various operations of addition, subtraction, multiplication, division, evolution and involution of the vectors A and B in Fig. 32, will be performed.

Addition.—Figure 33 illustrates the addition of these vectors expressed in rectangular co-ordinates. The resulting vector will have as its real component the

* For an extended explanation of j terms, reference is made to Dr. Charles P. Steinmetz's "Engineering Mathematics," and Dr. A. E. Kennelly's "Artificial Electric Lines."

algebraic sum of the reals, and as its imaginary component the algebraic sum of the imaginaries. Thus,

$$\begin{aligned} A &= +4 + j3 \\ +B &= \underline{+2 + j4} \\ A + B = C &= +6 + j7 \\ C &= \sqrt{(6)^2 + (7)^2} = 9.22 \text{ absolute.} \end{aligned}$$



FIGS. 29 to 36.—Examples of vector solutions.

The resulting vector has, therefore, a size of 9.22 units and is inclined in the forward direction at a slope of 49° 24′ with reference to the initial line, *OS*.

Subtraction.—Figure 34 illustrates the subtraction $A - B$. This is simply addition after the signs of both of the components of the vector to be subtracted have been reversed. Thus,

$$\begin{aligned} A &= +4 + j3 \\ -B &= \underline{-2 - j4} \\ A - B = C &= +2 - j1 \\ C &= \sqrt{(2)^2 + (1)^2} = 2.24 \text{ absolute.} \end{aligned}$$

The resulting vector C has therefore a size of 2.24 units and a slope of $-26°\ 34'$. In polar co-ordinates, $C = 2.24 \diagdown\!\overline{26°\ 34'}$.

Division.—To divide one plane vector by another, divide their sizes and subtract their slopes, Fig. 35.

Thus,

$$\text{Absolute value of } C = \frac{5}{4.47} = 1.12$$

Angle of inclination of $C = 36° 52' - 63° 26' = -26° 34'$ in the negative direction. In polar co-ordinates $C = 1.12 \diagdown 26° 34'$.

Or, in complex numbers, the rule may be stated—to evaluate a complex fraction multiply the numerator by the conjugate of the denominator (the denominator with the sign of its j term changed), and divide the product by the sum of the squares of the real and imaginary terms of the denominator. Thus

$$\begin{aligned} C &= \frac{4 + j3}{2 + j4} \\ &= \frac{(4 + j3)\ (2 - j4)}{2^2 \quad + \quad 4^2} \\ &= \frac{20 - j10}{20} \\ &= 1 - j.5 \\ &= 1.12 \diagdown 26° 34' \end{aligned}$$

Multiplication.—Figure 36 illustrates the multiplication of the vectors A and B. Here the rules of algebra also apply, except that when two j terms are multiplied signs are assigned opposite to those which would be used in the ordinary solution of an algebraic problem. This is for the reason that,

$$j = \sqrt{-1}$$

hence,

$$j^2 = -1$$

Hence where j^2 occurs it is replaced by its value -1 and therefore,

$$\begin{aligned} -j \times j &= +1 \\ j^3 &= -j \\ j^4 &= +1 \\ j^5 &= +j, \text{ etc.} \end{aligned}$$

Thus, to get the product of A and B,

$$\begin{aligned} A &= +4 + j3 \\ B &= +2 + j4 \\ & \quad +8 + j6 \\ & \quad -12 + j16 \\ A \times B = C &= -4 + j\,22 = 22.35 \text{ absolute.} \end{aligned}$$

The resulting vector C has therefore a size of 22.35 units and is inclined in the positive direction at an angle of 100° 18′ to the vector of reference. The polar expression is $C = 22.35 \diagdown 100° 18'$.

The magnitude and position of the product may be also determined by multiplying the sizes of the vectors and adding their slopes. Thus,

$$\text{Size of } C = 5 \times 4.47 = 22.35 \text{ (as above)}$$
$$\text{Slope of } C = 63° 26' + 36° 52' = 100° 18'.$$

Involution.—Involution is multiple multiplication. To obtain the power of a plane vector, find the power of the polar value and multiply the angle by the power to which the vector is to be raised. Thus, —vector $A = 5 \underline{/36° 52'}$; and $(5 \underline{/36° 52'})^2 = 5^2 \underline{/73° 44'} = 25 \underline{/73° 44'}$.

Evolution.—To find the root of a polar plane vector, find the root of the polar value and then divide the slope by the root desired. Thus vector $A = 5 \underline{/36° 52'}$; and $\sqrt{5 \underline{/36° 52'}} = 2.236 \underline{/18° 26'}$.

SOLUTION BY CONVERGENT SERIES

The hyperbolic formula for determining the operating characteristics of a transmission circuit in which exact account is taken of all the electric properties of the circuit is frequently expressed in the following form.

$$E_s = E_r \cosh \sqrt{ZY} + I_r \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY} \tag{51}$$

$$I_s = I_r \cosh \sqrt{ZY} + E_r \frac{1}{\sqrt{\frac{Z}{Y}}} \sinh \sqrt{ZY} \tag{52}$$

Since $\sqrt{ZY}$ is complex, the hyperbolic functions of complex quantities are required in solving these equations.

In above formula, expressed in hyperbolic language, the three auxiliary constants A, B and C which take into account the "distributed" nature of the circuit are represented by the quantities,

$$A = \text{Cosh} \sqrt{ZY} \tag{53}$$

$$B = \sqrt{\frac{Z}{Y}} \sinh \sqrt{ZY} \tag{54}$$

$$C = \frac{1}{\sqrt{\frac{Z}{Y}}} \sinh \sqrt{ZY} \tag{55}$$

Equations (51) and (52) above may therefore be expressed in terms of the auxiliary constants, A, B and C, as follows,

$$E_s = E_r A + I_r B \tag{56}$$
$$I_s = I_r A + E_r C \tag{57}$$

or

$$E_r = E_s A - I_s B \tag{58}$$
$$I_r = I_s A - E_s C \tag{59}$$

These three auxiliary constants may be calculated by convergent series as follows;

$$A = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40{,}320} + \text{etc.}\right] \tag{60}$$

$$B = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \text{etc.}\right] \tag{61}$$

$$C = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \text{etc.}\right] \tag{62}$$

The above series are simply expressions for the auxiliary constants as previously stated. These constants are functions of the physical properties of the circuit and of the frequency only, and not of the voltage or the current. After the values for the auxiliary constants have been calculated for a given circuit and frequency, their numerical values may be applied directly to any numerical values of E and I for which a solution is desired. From this point on, the performance of the circuit may be determined either by the graphical method previously described or by mathematical calculation.

Any degree of accuracy may be obtained by the use of convergent series for determining the auxiliary constants, by simply using a sufficient number of terms in the series. The rapidity of convergence of these series

is dependent upon the value of the argument ZY and thus upon the square of the length of the circuit and frequency, and also, to a lesser extent upon the product of total circuit conductance and total circuit resistance.

As far as calculations based upon the more or less uncertain values of the fundamental constants of the circuit are concerned, the use of three terms in the series expression yields results in a 300-mile circuit which are sufficiently close to the exact values as given by the use of hyperbolic functions (infinite number of terms). In the case of shorter circuits two terms will give a high degree of accuracy. The number of terms necessary will be determined while doing the work, for it is usual to figure out the terms of the series until they become too small to be considered when added to $YZ/2$ or $YZ/6$.

In Table N are given values for the auxiliary constants (expressed in rectangular co-ordinates) illustrating the convergence of the series for a 300-mile, 60-cycle circuit (Problem X), the complete calculation of which will follow.

Table N shows that even for a 60-cycle, 300-mile circuit, three terms give sufficiently accurate results for determining constant A, whereas two terms are sufficient for determining constants B and C. This is on account of the slower convergence of the hyperbolic cosine series.

Table N.—Convergent Series Terms for Problem X

No. of terms	Constant A	Constant B	Constant C
1	$1.000000 + j0.000000$	$105 + j249$	$0 \quad + j0.001563$
2	$+0.805407 + j0.082057$	$+91.3788 + j235.7211$	$-0.000043 + j0.001462$
3	$+0.810596 + j0.076735$	$+91.7527 + j235.8678$	$-0.000041 + j0.001463$
4	$+0.810558 + j0.076832$	$+91.7486 + j235.8680$	$-0.000041 + j0.001463$
Infinite	$+0.810558 + j0.076831$	$+91.7486 + j235.8680$	$-0.000041 + j0.001463$

CALCULATION FOR THE AUXILIARY CONSTANTS BY CONVERGENT SERIES

The form of solution and procedure indicated in Chart XI for the calculation of the auxiliary constants by convergent series is suggested as being complete and easy to follow.

First the physical characteristics of the circuit and the frequency are stated. These are the only features having any bearing upon the value of the auxiliary constants for a given circuit. The voltage and current to be transmitted do not affect these constants. The resistance, reactance, conductance, and susceptance to neutral per mile are ascertained from the tables for one conductor of the circuit. These values are then multiplied by the length of the circuit in miles and set down as total per conductor.

The values of Y and Z must now be set down for the problem in the form of complex quantities. Thus $Z = R + jX = 105 + j249$ and $Y = G + jB \doteq 0 + j0.001563$ since zero leakage conductance has been assumed for this case. Conductance G represents the true power loss in the form of leakage over insulators and of corona loss through the air between conductors. Corona loss corresponding to the assumed atmospheric conditions may be estimated by applying Peek's formula (See Chapter IV on Corona). Insulator leakage may be approximated from the most suitable test data available. It is general practice in the solution of all but the very longest high-voltage circuits to ignore the effect of the losses due to leakage and corona effect. These losses will be ignored in this case, so that G becomes zero. After Z and Y have been written down in the form of complex quantities the product YZ should be found as previously described for the multiplication of complex quantities. The second, third and fourth power of YZ may then be found, if desired. Chart XI shows the fourth power, but on all but the longest circuits a total of four terms will be sufficient, and for most problems three terms will give sufficient accuracy. The range of accuracy has been previously indicated for a 300-mile circuit on the basis of any number of terms being used up to and including infinity. The values in Chart XI are carried out to six decimal places whereas four places will usually give sufficient accuracy for calculating the values of the constants A and B. The smallness of the value of constant C may make six places desirable when calculating its value.

After the values of YZ, Y^2Z^2, Y^3Z^3 etc., have been calculated they are divided by 2, 24, 720 etc., respectively, set down and added to 1. This gives the value of the auxiliary constant A, as $+0.810558 + j\,0.076831$ which is also referred to as $a_1 + ja_2$. The absolute value of the constant $A = 0.8142$ is simply the square root of the sum of the square of a_1 and a_2. The polar value of A is thus $0.8142 \underline{/5° 24'} 53''$.

The solution for the constant B is of the same general form as the solution for the constant A, except that the values of YZ, Y^2Z^2, and Y^3Z^3 etc., are divided by 6, 120 and 5040 respectively. After these results are added to 1 they are multiplied by Z, the product being the value of the auxiliary constant B or $b_1 + jb_2$. The absolute value of B is obtained in the same manner as the absolute value of A.

The solution for C is the same as for B except that in place of the constant B series being multiplied by Z it is multiplied by Y and the values of C or $c_1 + jc_2$ obtained.

CHART XI—EXAMPLE ILLUSTRATING RIGOROUS SOLUTION FOR THE AUXILIARY CONSTANTS BY CONVERGENT SERIES FOR PROBLEM X

PHYSICAL CHARACTERISTICS OF CIRCUIT — FREQUENCY

LENGTH, 300 MILES. CYCLES, 60.
CONDUCTORS — #000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUIVALENT DELTA SPACING = 12.6 FEET.

LINEAR LINE CONSTANTS

FROM TABLES — PER MILE

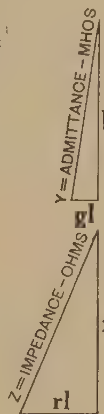
TABLE NO. 2, $\mathbf{r} = .350$ OHM AT 25° C.
TABLE NO. 5, $\mathbf{x} = .830$ OHM (BY INTERPOLATION).
TABLE NO. 10 $\mathbf{b} = 5.21 \times 10^{-6}$ MHO (BY INTERPOLATION).
$\mathbf{g} =$ (IN THIS CASE TAKEN AS ZERO).

TOTAL PER CONDUCTOR

$R = \mathbf{rl} = .350 \times 300 = 105$ OHMS TOTAL RESISTANCE.
$X = \mathbf{xl} = .830 \times 300 = 249$ OHMS TOTAL REACTANCE.
$B = \mathbf{bl} = 5.21 \times 300 \times 10^{-6} = .001563$ MHO TOTAL SUSCEPTANCE.
$G = \mathbf{gl} = 0 \times 300 = 0$ MHO TOTAL CONDUCTANCE.

MULTIPLICATION OF YZ

Y =		0	+ j .001563
Z =		105	+ j 249
		0	0
	−	.389187	+ j .164115
YZ =	−	.389187	+ j .164115
YZ =	−	.389187	+ j .164115
	+	.151466	− j .063871
	−	.026934	− j .063871
Y^2Z^2 =	+	.124532	− j .127742
YZ =	−	.389187	+ j .164115
	−	.048466	+ j .020437
	+	.020964	+ j .049715
Y^3Z^3 =	−	.027502	+ j .070152
YZ =	−	.389187	+ j .164115
	+	.010703	− j .004513
	−	.011513	− j .027302
Y^4Z^4 =	−	.000810	− j .031815



NOTE

THE AUXILIARY CONSTANTS OF THE CIRCUIT (A) (B) & (C) MAY BE OBTAINED GRAPHICALLY FROM THE WILKINSON CHARTS

SOLUTION FOR (A)

$$(A) = \left[1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40{,}320} + \right].$$

		1.000 000	
$\frac{YZ}{2}$ =	−	.194593	+ j .082057
$\frac{Y^2Z^2}{24}$ =	+	.005189	− j .005322
$\frac{Y^3Z^3}{720}$ =	−	.000038	+ j .000097
$\frac{Y^4Z^4}{40{,}320}$ =	−	.000000	− j .000001
(A) =	+	.810558	+ j .076831
=		$(a_1 + j a_2)$	
=		0.8142 /5° 24′ 53″	

SOLUTION FOR (B)

$$(B) = Z\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \right].$$

		1.000 000	
$\frac{YZ}{6}$ =	−	.064863	+ j .027352
$\frac{Y^2Z^2}{120}$ =	+	.001038	− j .001064
$\frac{Y^3Z^3}{5{,}040}$ =	−	.000005	+ j .000014
$\frac{Y^4Z^4}{362{,}880}$ =	−	.000000	− j .000000
(B) = Z (+		.93617	+ j .026302)
Z =		105	+ j 249
	+	98.2978	+ j 233.1063
	−	6.5492	+ j 2.7617
(B) =	+	91.7486	+ j 235.8680
=		$(b_1 + j b_2)$	
		= 253.083 /68° 44′ 41″ OHMS	

SOLUTION FOR (C)

$$(C) = Y\left[1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \right]$$

(C) = Y (+		93617	+ j 026302)
Y =		0	+ j 001563
(C) =	−	.000041	+ j 001463
=		$(c_1 + j c_2)$	
		= .001464 \ 91° 36′ 18″ MHO	

AUXILIARY CONSTANTS OF VARIOUS CIRCUITS

In Chart XII are tabulated exact values for the auxiliary constants for the 64 problems to which frequent reference will be made. These auxiliary constants have been calculated by convergent series, the results having been checked through the medium of three separate calculations made at different times. They are therefore believed exact to at least five significant digits. The results have been expressed in both rectangular and polar co-ordinates.

CALCULATIONS OF PERFORMANCE

In Chart XIII is given the complete calculation of the electrical performance for problem X, starting with the values for the auxiliary constants and the receiving end load conditions known. The calculations are carried out by the employment of complex numbers, the complete performance being calculated for both load and zero load conditions. In order to give a more clear understanding of these mathematical operations the reader is referred to the vector diagrams of Fig. 37.

In Chart XIII are given the formulae for determining the E_s and I_s values under load conditions. On Fig. 37 these two same formulae are given, but in the form of vector diagrams, upon which vectors the numerical values corresponding to problem X are stated. With the numerical values of the vectors and angles stated, it should be a comparatively simple manner to follow graphically (Fig. 37) the mathematical calculations shown in Chart XIII.

The formulae for E_s and I_s which are stated in Chart XIII and in Fig. 37 contain a complex number ($\cos \theta_r \pm j \sin \theta_r$) not previously stated in connection with the fundamental hyperbolic formulas for long circuits. The formulas previously given were based upon unity power-factor. The introduction of this new com-

CHART XII—AUXILIARY CONSTANTS OF VARIOUS CIRCUITS

PROBLEM NO.	LENGTH OF CIRCUIT–(MILES)	CONDUCTORS	SPACING–DELTA	LINEAR CONSTANTS TOTAL PER CONDUCTOR ★ rl	xl	bl	gl	AUXILIARY CONSTANTS OF CIRCUIT — THESE AUXILIARY CONSTANTS TAKE INTO ACCOUNT THE EFFECT OF DISTRIBUTED CAPACITANCE. THEY HAVE BEEN CALCULATED RIGOROUSLY BY CONVERGENT SERIES. CONSTANT (A) a_1 a_2	CONSTANT (B) b_1 b_2	CONSTANT (C) c_1 c_2
								25 CYCLES		
1	20	0000 COPPER	3	5.54	5.36	57.2	0	.999847 + j.000158	5.5394 + j 5.3600	0 + j.000057
2	"	"	"	"	"	"	0	= .999847 ∠0°0'32"	= 7.7081 ∠44°3'27"	= .000057 ∠90°0'0"
3	"	"	3	5.54	5.36	57.2	0	.999847 + j.000158	5.5394 + j 5.3600	0 + j.000057
4	"	"	"	"	"	"	0	= .999847 ∠0°0'32"	= 7.7081 ∠44°3'27"	= .000057 ∠90°0'0"
5	30	0000 COPPER	4	8.31	8.5	81.0	0	.999656 + j.000336	8.3082 + j 8.4999	0 + j.000081
6	"	"	"	"	"	"	0	= .999656 ∠0°1'10"	= 11.886 ∠45°39'12"	= .000081 ∠90°0'0"
7	"	"	4	8.31	8.5	81.0	0	.999656 + j.000336	8.3082 + j 8.4999	0 + j.000081
8	"	"	"	"	"	"	0	= .999656 ∠0°1'10"	= 11.886 ∠45°39'12"	= .000081 ∠90°0'0"
9	50	0000 COPPER	4	13.85	14.1	135	0	.999048 + j.000935	13.841 + j 14.0996	0 + j.000135
10	"	"	"	"	"	"	0	= .999048 ∠0°3'12"	= 19.757 ∠45°31'44"	= .000135 ∠90°0'0"
11	"	"	6	13.85	15.1	125	0	.999056 + j.000866	13.8413 + j 15.0991	0 + j.000125
12	"	"	"	"	"	"	0	= .999056 ∠0°2'58"	= 20.4833 ∠47°29'20"	= .000125 ∠90°0'0"
13	100	0000 COPPER	9	27.7	32.2	233	0	.996248 + j.003224	27.6307 + j 32.1894	0 + j.000233
14	"	"	"	"	"	"	0	= .996253 ∠0°11'7"	= 42.4218 ∠49°21'28"	= .000233 ∠90°0'0"
15	"	"	11	27.7	33.2	226	0	.996249 + j.003126	27.6308 + j 33.1874	0 + j.000226
16	"	"	"	"	"	"	0	= .996254 ∠0°10'47"	= 43.1841 ∠50°13'13"	= .000226 ∠90°0'0"
17	200	300M COPPER	11	39.2	64.8	464	0	.984991 + j.009049	38.808 + j 64.594	−.000001 + j.000462
18	"	"	"	"	"	"	0	= .985033 ∠0°31'35"	= 75.356 ∠59°0'10"	= .000462 ∠90°7'27"
19	"	"	17	39.2	69.2	434	0	.985009 + j.008464	38.8084 + j 68.965	−.000001 + j.000432
20	"	"	"	"	"	"	0	= .985050 ∠0°29'31"	= 79.134 ∠60°37'58"	= .000432 ∠90°7'54"
21	300	636M ALUM.	11	44.1	91.2	747	0	.966085 + j.016285	43.1033 + j 90.408	−.000004 + j.000739
22	"	"	"	"	"	"	0	= .966222 ∠0°57'1"	= 100.157 ∠64°30'36"	= .000739 ∠90°17'10"
23	"	"	21	44.1	101	672	0	.966219 + j.014650	43.1070 + j 100.077	−.000003 + j.000664
24	"	"	"	"	"	"	0	= .966330 ∠0°52'6"	= 108.966 ∠66°41'48"	= .000664 ∠90°15'24"
25	400	636M ALUM.	17	58.8	130	928	0	.940161 + j.026738	56.4555 + j 127.927	−.000008 + j.000909
26	"	"	"	"	"	"	0	= .940541 ∠1°37'45"	= 139.83 ∠66°11'16"	= .000909 ∠90°30'14"
27	"	"	21	58.8	134	896	0	.940452 + j.025819	56.4664 + j 131.842	−.000008 + j.000878
28	"	"	"	"	"	"	0	= .940801 ∠1°34'20"	= 143.425 ∠66°48'54"	= .000878 ∠90°31'18"
29	500	636M ALUM.	17	73.5	163	1160	0	.906642 + j.041299	68.928 + j 158.928	−.000016 + j.001124
30	"	"	"	"	"	"	0	= .907583 ∠2°36'14"	= 173.23 ∠66°33'13"	= .001124 ∠90°48'56"
31	"	"	21	73.5	168	1120	0	.907109 + j.039880	68.9507 + j 163.76	−.000015 + j.001085
32	"	"	"	"	"	"	0	= .907985 ∠2°31'2"	= 177.684 ∠67°10'0"	= .001085 ∠90°47'33"
								60 CYCLES		
33	20	0000 COPPER	3	5.54	12.88	137	0	.999118 + j.000379	5.53675 + j 12.8769	0 + j.000137
34	"	"	"	"	"	"	0	= .999118 ∠0°1'18"	= 14.0167 ∠66°44'0"	= .000137 ∠90°0'0"
35	"	"	3	5.54	12.88	137	0	.999118 + j.000379	5.53675 + j 12.8769	0 + j.000137
36	"	"	"	"	"	"	0	= .999118 ∠0°1'18"	= 14.0167 ∠66°44'0"	= .000137 ∠90°0'0"
37	30	0000 COPPER	4	8.31	20.4	195	0	.998011 + j.00081	8.299 + j 20.3887	0 + j.000195
38	"	"	"	"	"	"	0	= .998011 ∠0°2'47"	= 22.014 ∠67°51'6"	= .000195 ∠90°0'0"
39	"	"	4	8.31	20.4	195	0	.998011 + j.00081	8.299 + j 20.3887	0 + j.000195
40	"	"	"	"	"	"	0	= .998011 ∠0°2'47"	= 22.014 ∠67°51'6"	= .000195 ∠90°0'0"
41	50	0000 COPPER	4	13.85	34.0	324	0	.994496 + j.002239	13.7992 + j 33.9479	0 + j.000323
42	"	"	"	"	"	"	0	= .994498 ∠0°7'33"	= 36.645 ∠67°52'45"	= .000323 ∠90°0'0"
43	"	"	6	13.85	36.4	301	0	.994526 + j.002081	13.7994 + j 36.3432	0 + j.000300
44	"	"	"	"	"	"	0	= .994528 ∠0°7'14"	= 38.874 ∠69°12'30"	= .000300 ∠90°0'0"
45	100	0000 COPPER	9	27.7	77.4	562	0	.97832 + j.007728	27.2996 + j 76.9116	−.000001 + j.000558
46	"	"	"	"	"	"	0	= .97835 ∠0°27'10"	= 81.6129 ∠70°27'36"	= .000558 ∠90°6'11"
47	"	"	11	27.7	79.7	542	0	.97847 + j.007452	27.302 + j 79.1963	−.000001 + j.000538
48	"	"	"	"	"	"	0	= .978498 ∠0°26'14"	= 83.77 ∠70°58'30"	= .000538 ∠90°6'27"
49	200	300M COPPER	11	39.2	156	1116	0	.914128 + j.021243	36.9541 + j 151.791	−.000008 + j.001084
50	"	"	"	"	"	"	0	= .914375 ∠1°19'31"	= 156.224 ∠76°19'2"	= .001084 ∠90°25'23"
51	"	"	17	39.2	166	1044	0	.914524 + j.019876	36.9641 + j 161.507	−.000007 + j.001014
52	"	"	"	"	"	"	0	= .914740 ∠1°14'40"	= 165.69 ∠77°6'31"	= .001014 ∠90°23'43"
53	300	636M ALUM.	11	44.1	220	1794	0	.808816 + j.037006	38.4655 + j 206.359	−.000023 + j.001678
54	"	"	"	"	"	"	0	= .809662 ∠2°37'0"	= 209.913 ∠79°26'28"	= .001678 ∠90°47'8"
55	"	"	21	44.1	243	1614	0	.810022 + j.033307	38.5002 + j 227.918	−.000018 + j.001510
56	"	"	"	"	"	"	0	= .810701 ∠2°21'14"	= 231.147 ∠80°24'43"	= .001510 ∠90°4'6"
57	400	636M ALUM.	17	58.8	314	2212	0	.671701 + j.057759	45.8726 + j 280.04	−.000044 + j.001958
58	"	"	"	"	"	"	0	= .674179 ∠4°54'54"	= 283.77 ∠80°41'50"	= .001959 ∠91°18'0"
59	"	"	21	58.8	322	2152	0	.672455 + j.056208	45.9013 + j 287.194	−.000042 + j.001912
60	"	"	"	"	"	"	0	= .674800 ∠4°46'39"	= 290.839 ∠80°55'10"	= .001913 ∠91°15'21"
61	500	636M ALUM.	17	73.5	390	2785	0	.502772 + j.084790	48.9614 + j 325.247	−.000085 + j.002307
62	"	"	"	"	"	"	0	= .509871 ∠9°34'20"	= 328.912 ∠81°26'21"	= .002309 ∠92°6'32"
63	"	"	21	73.5	402	2690	0	.504852 + j.081969	49.061 + j 335.414	−.000079 + j.002230
64	"	"	"	"	"	"	0	= .511463 ∠9°13'12"	= 338.98 ∠81°40'43"	= .002232 ∠92°1'45"

* *rl* is the resistance in ohms at 25°C. (77°F.), *xl* the reactance in ohms, *bl* the susceptance in micromhos to neutral (multiply by 10^{-6} to convert to mhos). The *x* and *b* values for the 636,000 circ. mil aluminum cable were taken as those of 700,000 circ. mil copper on the assumption that these two conductors would have approximately the same diameter. *gl*, the loss resulting from leakage over insulators and from corona has, for simplicity, been assumed as zero. The values for these linear constants were taken from some old (now superseded) tables.

CHART XIII—RIGOROUS CALBULATION OF PERFORMANCE WHEN RECEIVING END CONDITIONS ARE FIXED

$KV\text{-}A_R = 18\ 000.$ $KW_R = 16\ 200.$ $E_R = 104\ 000$ VOLTS 3 PHASE. $PF_R = 90.00\%$ LAGGING.

PER PHASE TO NEUTRAL

$KV\text{-}A_{RN} = \frac{18\ 000}{3} = 6\ 000.$ $KW_{RN} = \frac{16\ 200}{3} = 5\ 400.$ $E_{RN} = \frac{104\ 000}{1.732} = 60\ 046.$ $I_R = \frac{6\ 000 \times 1000}{60\ 046} = 99.92$ AMPERES.

AUXILIARY CONSTANTS OF CIRCUIT

$(A) = +.810558 + j.076831 = (a_1 + j a_2) = .8142\ \underline{/5°\ 24'\ 53''}$

$(B) = +91.7486 + j\ 235.868 = (b_1 + j\ b_2) = 253.083\ \underline{/68°\ 44'\ 41''}$ OHMS

$(C) = -.000041 + j.001463 = (c_1 + j\ c_2) = .001464\ \underline{\backslash 91°\ 36'\ 18''}$ MHO

LOAD CONDITIONS

SOLUTION FOR E_S

$E_S = E_R(a_1 + j a_2) + I_R(\cos\theta_R \pm j \sin\theta_R)(b_1 + j b_2)$ ★

★ ± THIS SIGN IS MINUS WHEN THE P. F. IS LAGGING AND PLUS WHEN THE P. F. IS LEADING

$(a_1 + j a_2)$	=	$+.810558 + j.076831$
$\times E_{RN}$	=	60046
$E_{RN}(a_1 + j a_2)$	=	$+ 48671 + j\ 4613$
$(\cos\theta_R - j \sin\theta_R)$	=	$+ .9 - j .436$
$\times I_R$	=	99.92
$I_R(\cos\theta_R - j \sin\theta_R)$	=	$+ 89.93 - j\ 43.56$
$\times (b_1 + j\ b_2)$	=	$+ 91.75 + j\ 235.87$
		$+ 8251 + j\ 21212$
		$+ 10274 - j\ 3997$
$I_R(\cos\theta_R - j \sin\theta_R)(b_1 + j b_2)$	=	$+ 18525 + j\ 17215$
$+ E_{RN}(a_1 + j a_2)$	=	$+ 48671 + j\ 4613$
E_{SN}	=	$+ 67196 + j\ 21828$
	=	$\sqrt{(67196)^2 + (21828)^2}$
E_{SN}	=	70 652 VOLTS TO NEUTRAL.

SOLUTION FOR I_S

$I_S = I_R(\cos\theta_R \pm j \sin\theta_R)(a_1 + j a_2) + E_R(c_1 + j c_2)$ ★

$I_R(\cos\theta_R - j \sin\theta_R)$	=	$+ 89.93 - j\ 43.56$
$\times (a_1 + j a_2)$	=	$+ .810558 + j .076831$
		$+ 72.893 + j\ 6.909$
		$+ 3.347 - j\ 35.308$
$I_R(\cos\theta_R - j \sin\theta_R)(a_1 + j a_2)$	=	$+ 76.240 - j\ 28.399$
$(c_1 + j c_2)$	=	$-.000041 + j .001463$
$\times E_{RN}$	=	60046
$E_{RN}(c_1 + j c_2)$	=	$- 2.462 + j\ 87.85$
$+ I_R(\cos\theta_R - j \sin\theta_R)(a_1 + j a_2)$	=	$+ 76.240 - j\ 28.399$
I_S	=	$+ 73.778 + j\ 59.451$
	=	$\sqrt{(73.778)^2 + (59.451)^2}$
I_S	=	94.75 AMPERES.

$KW_{SN} = (67.196 \times 73.778) + (21.828 \times 59.451) = 6.255$ KW PER PHASE. EFFICIENCY $= \frac{5\ 400 \times 100}{6\ 255} = 86.33\%$.

$KV\text{-}A_{SN} = (70.652 \times 94.75) = 6\ 694$ KV-A PER PHASE. $PF_S = \frac{6\ 255 \times 100}{6\ 694} = 93.42\%$ LEADING.

$LOSS_N = 6255 - 5400 = 855$ KW PER PHASE.

PHASE ANGLES— AT FULL LOAD THE VOLTAGE AT THE SENDING END LEADS THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $\tan^{-1}\frac{21\ 828}{67196} = \tan^{-1}.325 = 18°\ 00'$. AND THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE RECEIVING-END BY THE ANGLE $\tan^{-1}\frac{59.451}{73.778} = \tan^{-1}.806 = 38°\ 52'$. HENCE THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE SENDING-END BY THE ANGLE $38°\ 52' -$ ANGLE $18°00' = 20°\ 52'$. THE POWER-FACTOR AT THE SENDING-END IS THEREFORE COS $20°\ 52' = 93.42\%$ LEADING AT LOAD SPECIFIED.

ZERO LOAD CONDITIONS

$E_{SNO} = 48671 + j\ 4613 = \sqrt{(48671)^2 + (4613)^2}$

$E_{SNO} = 48\ 889$ VOLTS.

$I_{SO} = -2.462 + j\ 87.85 = \sqrt{(-2.462)^2 + 87.85)^2}$

$I_{SO} = 87.89$ AMPERES.

$KW_{SNO} = (48.671 \times -2.462) + (4.613 \times 87.85) = 285.43$ KW PER PHASE.

$KV\text{-}A_{SNO} = 48.889 \times 87.89 = 4\ 297$ KV-A PER PHASE.

$PF_{SO} = \frac{285.43 \times 100}{4.297} = 6.64\%$ LEADING.

REGULATION

A RISE IN VOLTAGE AT THE SENDING-END OCCURS OF $70\ 652 - 48\ 889 = 21\ 763$ VOLTS TO NEUTRAL WHEN THE LOAD IS INCREASED FROM ZERO TO 99.92 AMPERES AT 90% POWER FACTOR LAGGING AT THE RECEIVER END WITH CONSTANT VOLTAGE AT THE RECEIVING END.

PHASE ANGLES

AT ZERO LOAD THE VOLTAGE AT THE SENDING-END LEADS THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $\tan^{-1}\frac{4.613}{48\ 671} = \tan^{-1}.0947 = 5°25'$ AND THE CURRENT AT THE SUPPLY END LEADS THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $\tan^{-1}\frac{87.86}{-2\ 462} = \tan(-35.7) = 91°\ 36'$—HENCE THE CURRENT AT THE SUPPLY END LEADS THE VOLTAGE AT THE SUPPLY END BY THE ANGLE $(91°\ 36') - (5°\ 25') = 86°11'$. THE POWER FACTOR AT THE SENDING-END IS THEREFORE COS $86°11' = 6.64\%$ LEADING AT ZERO LOAD.

plex number is made necessary in order that the effect of the power-factor of the load current may be included in the calculations. The function of this new complex number is to rotate the current vector through an angle corresponding to the power-factor of the load current. It will be referred to as the rotating triangle. If the load power-factor is 100 per cent, this rotating triangle will equal $1 \pm j0$, hence it has no effect or power to rotate. If the power-factor of the load is 80 per cent the rotating triangle would have a numerical value of $0.8 \pm j0.6$.

The various phase angles given in Chart XIII show whether the power-factor at the supply end is leading or lagging. These various phase angles are given to make the discussion complete. Actually, in order to determine whether the power-factor at the supply end is leading or lagging, it is only necessary to note if the supply-end current vector leads or lags behind the supply-end voltage vector. At the lower end of Fig. 37 combined current and voltage vectors are shown for this problem, corresponding to both load and zero load conditions.

In Chart XIV is given a complete calculation of the electrical performance of problem X, starting with the values for the auxiliary constants and the sending-end load conditon known. In other words the supply-end conditions which were derived by calculation in Chart XIII have in this case been assumed as fixed, and the

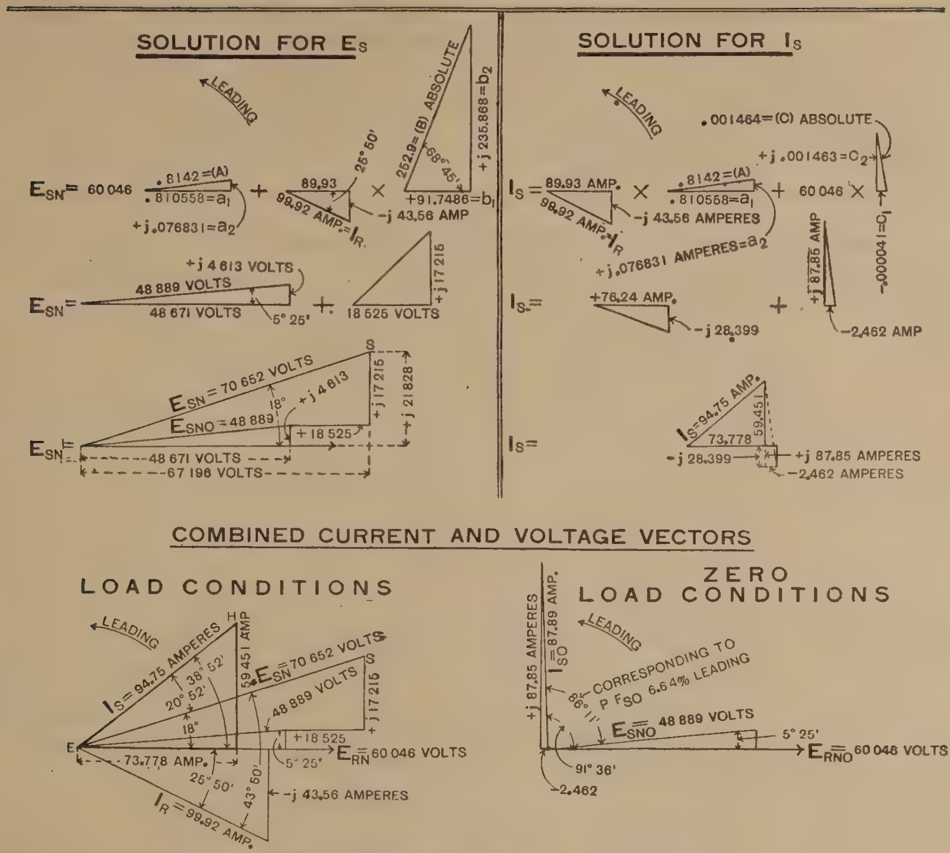


FIG. 37—GRAPHIC REPRESENTATION OF PROBLEM X
Illustrating rigorous calculations of performance when receiving end conditions are fixed.

receiver-end conditions calculated. The reason that there is a slight difference between the receiving-end conditions as calculated on Chart XIV and the known receiving-end conditions is that the value for the sine in the rotating triangle (0.436) in Chart XIII was carried out to only three places, whereas in Chart XIV it was carried out to four places. If the values for the rotating triangles had been carried out to five or six places in the calculations in both charts, the receiving end conditions would have checked exactly.

TERMINAL VOLTAGES AT ZERO LOAD

For a given circuit and frequency, the relation of the voltage at the two ends of the circuit is fixed. The ratio of sending end to the receiving end voltage is expressed by the constant A. The ratio of receiving to sending end voltage is expressed by $\frac{1}{A}$. For example, problem X, the sending-end voltage under load is 70,652 volts. If the load is thrown off, and this sending end voltage is maintained constant at 70,652 volts, the receiving-end voltage will rise to a value of 70,652/0.8142 = 86,775 volts to neutral. The rise in per cent of sending-end voltage is therefore

$$\frac{100 \times (86{,}775 - 70{,}652)}{70{,}652} = 22.82 \text{ per cent.}$$

PERFORMANCE OF VARIOUS CIRCUITS

In Chart XV is tabulated the complete performance of the 64 problems for which the auxiliary constants are tabulated in Chart XII. The auxiliary constants in Chart XII were applied to the fixed load conditions as stated in Chart XV for the receiving end, and both load and zero load conditions at the sending end were calculated and tabulated.

The object of calculating and tabulating the values for the 64 problems was two fold. First to obtain data on 25 and 60-cycle problems covering a wide range which would provide a basis for constructing curves, illustrating the effect that distance in transmission has upon the performance of circuits and upon the auxiliary constants of the circuit. Second, to give the student a wide range of problems from which he could choose, and from which he could start with the tabulated values as fixed at either end and calculate the conditions at the other end. It is believed that such problems will furnish very profitable practice for the student and will also serve as a general guide when making calculations on problems of similar length and fundamental or linear constants. It is not intended that the figures given for longer circuits, included in these tabulations, shall coincide with ordinary conditions encountered in practice.

CHART XIV—RIGOROUS CALCULATION OF PERFORMANCE WHEN SENDING END CONDITIONS ARE FIXED

$KV\text{-}A_S = 20\ 082.$ $KW_S = 18\ 765.$ $E_S = 122\ 369$ VOLTS 3 PHASE. $PF_S = 93.42\%$ LEADING.

PER PHASE TO NEUTRAL

$KV\text{-}A_{SN} = \frac{20\ 082}{3} = 6\ 694.$ $KW_{SN} = \frac{18\ 765}{3} = 6\ 255.$ $E_{SN} = \frac{122\ 369}{1.732} = 70\ 652.$ $I_S = \frac{6\ 694 \times 1000}{70\ 652} = 94.75$ AMPERES.

AUXILIARY CONSTANTS OF CIRCUIT

$(A) = +.810558 + j.076831 = (a_1 + j a_2) = .8142\ \underline{/5°\ 24'\ 53''}$

$(B) = +91.7486 + j\ 235.868 = (b_1 + j\ b_2) = 253.083\ \underline{/68°\ 44'\ 41''}$ OHMS

$(C) = -.000041 + j.001463 = (c_1 + j\ c_2) = .001464\ \underline{\backslash 91°\ 36'\ 18''}$ MHO

LOAD CONDITIONS

SOLUTION FOR E_R

$$E_R = E_S(a_1 + j a_2) - I_S(\cos\theta_S \pm j \sin\theta_S)(b_1 + j b_2)\bigstar$$

SOLUTION FOR I_R

$$I_R = I_S(\cos\theta_S \pm j \sin\theta_S)(a_1 + j a_2) - E_S(c_1 + j c_2)\bigstar$$

★ ± THIS SIGN IS MINUS WHEN THE P. F. IS LAGGING AND PLUS WHEN THE P. F. IS LEADING

$$\begin{aligned}
(a_1 + j a_2) &= +.810558 + j.076831 \\
\times E_{SN} &= +70652 \\
E_{SN}(a_1 + j a_2) &= +57268 + j\ 5428 \\
(\cos\theta_S + j \sin\theta_S) &= +.9342 + j.3567 \\
\times I_S &= +94.75 \\
I_S(\cos\theta_S + j \sin\theta_S) &= +88.52 + j\ 33.8 \\
\times (b_1 + j\ b_2) &= +91.75 + j\ 235.9 \\
& +8122 + 20882 \\
& -7973 + j\ 3101 \\
I_S(\cos\theta_S + j \sin\theta_S)(b_1 + j\ b_2) &= +149 + j\ 23983 \\
E_{SN}(a_1 + j a_2) &= +57268 + j\ 5428 \\
-I_S(\cos\theta_S + j \sin\theta_S)(b_1 + j\ b_2) &= -149 - j\ 23983 \\
E_{RN} &= +57119 - j\ 18555 \\
&= \sqrt{(57119)^2 + (18555)^2}
\end{aligned}$$

$E_{RN} = 60\ 057$ VOLTS TO NEUTRAL.

$$\begin{aligned}
I_S(\cos\theta_S + j \sin\theta_S) &= +88.52 + j\ 33.8 \\
\times (a_1 + j\ a_2) &= +.810558 + j.076831 \\
& +71.751 + j\ 6.801 \\
& -2.597 + j\ 27.397 \\
I_S(\cos\theta_S + j \sin\theta_S)(a_1 + j a_2) &= +69.154 + j\ 34.198 \\
(c_1 + j c_2) &= -.000041 + j.001463 \\
\times E_{SN} &= 70652 \\
E_{SN}(c_1 + j c_2) &= -2.897 + j\ 103.36 \\
I_S(\cos\theta_S + j \sin\theta_S)(a_1 + j a_2) &= +69.154 + j\ 34.20 \\
-E_{SN}(c_1 + j c_2) &= +2.897 - j\ 103.36 \\
I_R &= 72.051 - j\ 69.16 \\
&= \sqrt{(72.051)^2 + (69.16)^2}
\end{aligned}$$

$I_R = 99.87$ AMPERES.

CHANGE SIGNS AND ADD

$KW_{RN} = (57.119 \times 72.051) + (18.555 \times 69.16) = 5\ 399$ KW PER PHASE.

$KV\text{-}A_{RN} = (60.057 \times 99.87) = 5\ 998$ KV-A PER PHASE.

$LOSS_N = 6\ 255 - 5\ 399 = 856$ KW PER PHASE.

$PF_R = \frac{5\ 399 \times 100}{5\ 998} = 90.01\%$ LAGGING.

$EFFICIENCY = \frac{5\ 399 \times 100}{6\ 255} = 86.32\%.$

PHASE ANGLES AT FULL LOAD THE VOLTAGE AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{18\ 555}{57\ 119} = \tan^{-1} .325 = 18°\ 0'$; AND THE CURRENT AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{69.16}{72.051} = \tan^{-1} .959 = 43°50'$. HENCE THE CURRENT AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE RECEIVER END BY THE ANGLE $43°\ 50' - $ ANGLE $18°0' = 25°\ 50'$. THE POWER-FACTOR AT THE RECEIVER END IS THEREFORE $\cos 25°50' = 90\%$ LAGGING.

ZERO LOAD CONDITIONS

$$\underline{E_{RNO}} = \frac{E_{SNO}(a_1 - j a_2)}{(a_1^2 + a_2^2)} = \frac{48\ 898\,(.81056 - j.076831)}{(.81056)^2 + (.076831)^2} = \frac{39635 - j\ 3757}{.6629} = 59\ 790 - j\ 5667 = 60\ 058 \text{ VOLTS.}$$

$$\underline{I_{SO}} = E_{SNO}\frac{(c_1 a_1 + c_2 a_2) + j(c_2 a_1 - c_1 a_2)}{(a_1^2 + a_2^2)} = 48\ 898\ \frac{((-.000041 \times .81056) + (.001463 \times .076831)) + j((.001463 \times .81056) - (-.000041 \times .076831))}{.6629}$$

$$\underline{I_{SO}} = 48\ 898\ \frac{(+.0000792 + j.001189)}{.6629} = 48\ 898\,(.000119 + j.001794) = 48\ 898 \times .001798 = 87.92 \text{ AMPERES.}$$

REGULATION

A RISE IN VOLTAGE AT THE SENDING-END OCCURS OF $70\ 652 - 48\ 898 = 21\ 754$ VOLTS TO NEUTRAL WHEN THE LOAD IS INCREASED FROM ZERO TO 99.87 AMPERES AT 90.01% POWER FACTOR LAGGING AT THE RECEIVER END WITH CONSTANT VOLTAGE AT THE RECEIVING END.

PHASE ANGLES

AT ZERO LOAD THE VOLTAGE AT THE RECEIVER END LAGS BEHIND THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{5\ 667}{59\ 790} = \tan^{-1} .0948 = 5°25'$; AND THE CURRENT AT THE SENDING-END LEADS THE VOLTAGE AT THE SENDING-END BY THE ANGLE $\tan^{-1}\frac{.001794}{.000119} = \tan^{-1} 15.08 = 86°11'$. THE POWER-FACTOR AT THE SENDING-END IS THEREFORE $\cos 86°11' = 6.64\%$ LEADING AT ZERO LOAD.

CHART XV—CALCULATED PERFORMANCE OF VARIOUS CIRCUITS

PROBLEM	RECEIVING-END CONDITIONS FIXED							SENDING-END CONDITIONS—CALCULATED ★											
	LOAD CONDITIONS							LOAD CONDITIONS							ZERO LOAD				
			TO NEUTRAL					TO NEUTRAL							TO NEUTRAL				
	$KV\text{-}A_R$	E_R 3 PHASE	$KV\text{-}A_{RN}$	KW_{RN}	E_{RN}	I_R	PF_R %	$KV\text{-}A_{SN}$	KW_{SN}	E_{SN}	I_S	★★ PF_S %	LINE DROP IN % OF E_{RN}	LINE LOSS IN % OF KW_R	$KV\text{-}A_{SNO}$	KW_{SNO}	E_{SNO}	I_{SO}	PF_{SO} %
25 CYCLES																			
1	1300	10 000	433.3	346.6	5 774	75	80 LAG	474.63	377.52	6 347	74.78	79.53	−9.92	8.92	1.963		5 773	.34	
2	"	"	"	433.3	"	"	100	465.09	464.21	6 202	74.99	99.81	−7.41	7.13	"		"	"	
3	5000	20 000	1666.6	1333.3	11 550	144.4	80 LAG.	1821.9	1449.5	12 653	143.99	79.56	−9.55	8.71	7.622		11 548	.66	
4		"	"	1666.6	"	"	100	1786.3	1783.33	12 372	144.38	99.80	−7.12	7.00	"		"	"	
5	3500	20 000	1167	933	11 550	101	80 LAG	1278.6	1017.45	12 733	100.42	79.58	−10.24	9.05	10.85		11546	.94	
6	"	"	"	1167	"	"	100	1 253.5	1251.22	12 415	100.97	99.82	−7.49	7.22	"		"	"	
7	8000	30 000	2667	2 133	17 320	154	80 LAG.	2 928.2	2 329.8	19 125	153.11	79.56	−10.42	9.23	24.29		17 313	1.403	
8	"	"	"	2 667	"	"	100	2 869.8	2 860.5	18 640	153.96	99.68	−7.62	7.26	"		"	"	
9	5000	30 000	1667	1 333	17 320	96.2	80 LAG	1 817.3	1 459.2	19 184	94.73	80.29	−10.76	9.47	40.32		17 304	2.33	
10	"	"	"	1 667	"	"	100	1 796.4	1 794.2	18 685	96.14	99.88	−7.89	7.63	"		"	"	
11	20 000	60 000	6667	5 333	34 640	192.5	80 LAG	7 303.9	5 841.0	38 490	189.76	79.97	−11.11	9.53	149.8	.13	34 607	4.33	.09
12	"	"	"	6 667	"	"	100	7192.1	7 181.2	37 387	192.37	99.85	−7.93	7.71	"	"	"	"	"
13	22 000	88 000	7333	5 867	50 810	144.4	80 LAG	7 762.5	6 419.6	56 619	137.1	82.70	−11.43	9.42	599:3	1.94	50 620	11.84	.32
14	"	"	"	7 333	"	"	100	7 915.4	7 915.2	54 820	144.39	100.00	−7.89	7.94	"	"	"	"	"
15	40 000	120 000	13 333	10 667	69 290	192.5	80 LAG	14 106	11 648	77 147	182.85	82.58	−11.34	9.19	1081	3.39	69 030	15.66	.31
16	"	"	"	13 333	"	"	100	14 366	14 366	74 642	192.47	100.00	−7.73	7.75	"	"	"	"	"
17	25 000	120 000	8 333	6 667	69 290	120.3	80 LAG.	7 886.5	7156.1	76 754	102.75	90.74	−10.77	7.34	2185	15.29	68 253	32.01	.70
18	"	"	"	8 333	"	"	100	9 025.4	8913.0	73 401	122.96	98.75x	−5.93	6.96	"	"	"	"	"
19	40 000	140 000	13 333	10 667	80 830	165	80 LAG	13 270	11 610	91 761	144.52	87.49	−13.52	8.84	2780	17.44	79 622	34.92	.63
20	"	"	"	13 333	"	"	100	14459	14412	86 863	166.46	99.68x	−7.46	8.09	"	"	"	"	"
21	20 000	120 000	6 667	5 333	69290	96.2	80 LAG	5 683.2	5642.9	75 682	75.08	99.29	−9.22	5.81	3428	39.22	66 950	51.21	1.14
22	"	"	"	6 667	"	"	100	7 652.7	7 105.4	71 762	106.64	92.85x	−3.57	6.57	"	"	"	"	"
23	60 000	200 000	20 000	16 000	115 500	173.2	80 LAG	17 576	17 048	128 450	136.83	96.99	−11.21	6.55	8559	91.03	111 611	76.69	1.06
24	"	"	"	20 000	"	"	100	22287	21 381	120 574	184.84	95.98x	−4.39	6.90	"	"	"	"	"
25	20 000	140 000	6 667	5 333	80 830	82.5	80 LAG	5 959.3	5621.1	86 404	68.97	94.33x	−6.89	5.40	5585	109.6	76 024	73.47	1.96
26	"	"	"	6 667	"	"	100	8 808.9	7 165.1	81 647	107.89	81.34x	−1.01	7.47	"	"	"	"	"
27	50 000	200 000	16 667	13 333	115 500	144.4	80 LAG	14 295	14 222	127 267	112.32	99.49x	−10.19	6.67	11 018	202.04	108 663	101.4	1.84
28	"		"	16 667	"	"	100	20 322	18 066	118 833	171.01	88.90x	−2.89	8.40	"	"	"	"	"
29	15 000	140 000	5 000	4 000	80 830	61.86	80 LAG.	6 183.5	4 237	83 045	74.46	68.52x	−2.74	5.92	6 665	208.54	73 360	90.85	3.13
30	"	"	"	5 000	"	"	100	8 518.7	5 479	78 658	108.30	64.32x	+2.69	9.58	"	"	"	"	"
31	40 000	200 000	13 333	10 667	115 500	115.5	80 LAG	13 277	11 383	123 401	107.59	85.74x	−6.85	6.71	13 140	395.8	104 873	125.3	3.01
32	"	"		13 333	"	"	100	19 096	14 672	115 162	165.82	76.83x	+0.29	10.05	"	"	"	"	"
60 CYCLES																			
33	1 300	10 000	433.3	346.6	5 774	75	80 LAG.	499.03	377.44	6 702	74.46	75.63	−16.07	8.90	4.558		5 769	.79	
34	"	"	"	433.3	"	"	100	469.05	464.18	6 259	74.94	98.96	−8.40	7.13	"		"	"	
35	5 000	20 000	1 667	1 333	11 550	144.4	80 LAG.	1 911.02	1448.95	13 333	143.33	75.82	−15.44	8.70	18.23		11 540	1.5[illegible]	
36	"	"	"	1 667	"	"	100	1 800.6	1 783.3	12 480	144.28	99.04	−8.05	6.98	"		"	"	
37	3 500	20 000	1 167	933	11 550	101	80 LAG.	1 341.0	1 016.8	13 482	99.47	75.82	−16.73	8.98	25.93		11 527	2.25	
38	"	"	"	1 167	"	"	100	1 264.0	1 251.2	12 537	100.82	98.99	−8.55	7.22	"		"	"	
39	8 000	30 000	2 667	2 133	17 320	154	80 LAG	3 073.6	2 327.9	20 268	151.65	75.74	−17.02	9.13	58.43		17 286	3.38	
40	"	"	"	2 667	"	"	100	2 894.7	2 864.1	18 830	153.73	98.94	−8.72	7.39	"		"	"	
41	5 000	30 000	1 667	1 333	17 320	96.2	80 LAG	1 879.2	1 456.2	20 331	92.43	77.40	−17.38	9.24	96.29	.22	17225	5.59	.22
42	"	"	"	1 667	"	"	100	1 806.1	1 794.1	18 845	95.84	99.33	−8.80	7.62	"	"	"	"	"
43	20 000	60 000	6 667	5 333	34 640	192.5	80 LAG.	7 597.8	5 830.1	40 976	185.42	76.73	−18.29	9.32	357.9	.75	34450	10.39	.21
44	"	"	"	6 667	"	"	100	7 243.0	7 180.2	37 773	191.75	99.13	−9.05	7.70	"	"	"	"	"
45	22 000	88 000	7 333	5 867	50 810	144.4	80 LAG.	7 578.7	6 380.0	59 925	126.47	84.18	−17.94	8.74	1 409	8.62	49 710	28.35	.61
46	"	"	"	7 333	"	"	100	7 915.5	7 915.3	54 869	144.26	100.00	−7.99	7.94	"	"	"	"	"
47	44 000	120 000	13 333	10 667	69 290	192.5	80 LAG.	13 796	11 579	81 710	168.84	83.93	−17.92	8.55	2 528	14.49	67 800	37.28	.57
48	"	"	"	13 333	"	"	100	14 366	14 365	74 735	192.22	100.00	−7.86	7.74	"	"	"	"	"
49	25 000	120 000	8 333	6 667	69 290	120.3	80 LAG.	7 082.3	7 075.1	79 000	89.65	99.89	−14.01	6.12	4 759	75.47	63 357	75.11	1.59
50	"	"	"	8 333	"	"	100	9 473.0	8 949.6	70 599	134.18	94.47x	−1.89	7.40	"	"	"	"	"
51	40 000	140 000	13 333	10 667	80830	165	80 LAG	11 827	11 461	96 727	122.27	96.90	−19.67	7.44	6 060	89.78	73 938	81.96	1.48
52	"	"	"	13 333	"	"	100	14 666	14 438	84 862	172.82	98.44	−4.99	8.29	"	"	"	"	"
53	20 000	120 000	6 667	5 333	69290	96.2	80 LAG.	69728	5 626.6	72 747	93.85	80.69x	−4.99	5.50	6 523	208.8	56 101	116.27	3.20
54	"	"	"	6 667	"	"	100	9 061.7	7 239.4	63 810	142.01	79.89x	+7.91	8.59	"	"	"	"	"
55	60 000	200 000	20 000	16000	115 500	173.2	80 LAG.	18 728	16 908	126 541	148.00	90.28x	−9.56	5.68	16 330	476.4	93 636	174.4	2.92
56	"	"	"	20 000	"	"	100	24 796	21 658	109 189	227.09	87.34x	+5.47	8.29	"	"	"	"	"
57	20 000	140 000	6 667	5 333	80 830	82.5	80 LAG.	10 089	5 796.2	74 182	136.01	57.45x	+8.22	8.69	8626	545.8	54 494	158.3	6.33
58	"	"	"	6 667	"	"	100	11 014	7 539.6	64 377	171.08	68.45x	+20.35	13.09	"	"	"	"	"
59	50000	200 000	16 667	13 333	115 500	144.4	80 LAG.	21 139	14 343	113 606	186.07	67.85x	+1.64	7.58	17 217	1 057	77 939	220.9	6.14
60	"	"	"	16 667	"	"	100	23 946	18 757	96 987	246.84	78.35x	+16.03	12.54	"	"	"	"	"
61	15 000	140 000	5 000	4 000	80 830	61.86	80 LAG.	10 233	4 801.2	59 046	173.30	46.92x	+26.95	20.03	7 690	998.8	41 213	186.6	12.99
62	"	"	"	5 000	"	"	100	9 918.4	6 230.9	51 327	193.24	62.81x	+36.50	24.60	"	"	"	"	"
63	40 000	200 000	13 333	10 667	115 500	115.5	80 LAG.	21 948	12 248	93 725	234.17	55.80x	+18.81	14.82	15 223	1 907	59 074	257.7	12.52
64	"	"	"	13 333	"	"	100	21 750	16 020	80 106	271.52	73.66x	+30.64	20.15	"	"	"	"	"

The above performances are based upon values for the auxiliary constants as given on Chart XII.

CHAPTER X

PERFORMANCE OF LONG TRANSMISSION LINES BY HYPERBOLIC FUNCTIONS

In the consideration of the hyperbolic theory as applied to transmission circuits, the writer desires to express his high appreciation of the excellent literature already existing. Dr. A. E. Kennelly's pioneer work and advocacy of the application of hyperbolic functions to the solution of transmission circuits has been too extensive and well known to warrant a complete list of his contributions. His most important treatises are "Hyperbolic Functions Applied to Electrical Engineering," 1916; "Tables of Complex Hyperbolic and Circular Functions," 1914; "Chart Atlas of Hyperbolic Functions," 1914, which provides a ready means of obtaining values for complex functions, thus materially shortening and simplifying calculations, and "Artificial Electric Lines," 1917.

"Electrical Phenomena in Parallel Conductors" by Dr. Frederick Eugene Pernot, 1918, is an excellent treatise on the subject and contains valuable tables of logarithms of real hyperbolic functions from $x = 0$ to $x = 2.00$ in steps of 0.001.

An article "Long-line Phenomena and Vector Locus Diagrams" in the *Electrical World* of Feb. 1, 1919, p. 212, by Prof. Edy Velander is an excellent and valuable contribution on the subject, because of its simplicity in explaining complicated phenomena.

To employ hyperbolic functions successfully in the solution of transmission circuits it is not necessary for the worker to have a thorough understanding of how they have been derived. On the other hand it is quite desirable to understand the basis upon which they have been computed. A brief review of hyperbolic trigonometry is therefore given before taking up the solution of circuits

Circular angles derive their name from the fact that they are functions of the circle, whose equation is $x^2 + y^2 = 1$. Tabulated values of such functions are based upon a radius of unit length. The geometrical construction illustrating three of the functions, the sine, cosine and tangent of circular angles is indicated in Fig. 38. The angle AOP, indicated by full lines in the positive or counter-clockwise direction has been drawn to correspond to one radian. The radian is an angular unit of such magnitude that the length of the arc which subtends the radian is numerically equal to that of the radius of the circle. Thus, the number of radians in a complete circle is 2π. Expressed in degrees the radian is equal approximately to 57° 17′ 44.8″. The segment AOP of any angle AOP of one radian has an area equal to one-half the area of a unit square. Therefore the angle may be expessed in radians, as,

$$\frac{\text{Length of arc}}{\text{radius}} \text{ or } \frac{2 \times \text{area}}{(\text{radius})^2}$$

Circular functions are obtained as follows,

$$\text{Circular angle} = \frac{2 \times \text{area}}{(\text{radius})^2} \text{ radians}$$

$$\text{Sin } \theta = \frac{Y}{R}$$

$$\text{Cos } \theta = \frac{X}{R}$$

$$\text{Tan } \theta = \frac{Y}{X}$$

The variations in the circular functions, sine, cosine and tangent are indicated graphically in Fig. 39 for a complete revolution of 360°. Since for the second and each succeeding revolution these graphs would simply be repeated, circular functions are said to have a period equal to 2π radians. In other words, adding 2π to a circular angle expressed in radians does not change the value of a circular function.

REAL HYPERBOLIC ANGLES

Real hyperbolic angles derive their name because they are functions of an equilateral hyperbola. A hyperbola is a plane curve, such that the difference between the distances from any point on the curve to two fixed points called the foci is constant. In an equilateral hyperbola, Fig. 40, the asymptotes OS and OS' are straight lines at right angles to each other and make equal angles with the X-axis. The hyperbola continually approaches the asymptotes, and meets them at infinity. The equation of such a hyperbola is $x^2 - y^2 = 1$.

The hyperbolic angle AOP of Fig. 40, called for convenience θ,* has been drawn so as to correspond to an angle of one hyperbolic radian, or one "hyp" as it is usually designated. Hyperbolic angles are determined by the area of the sector they enclose. Thus the hyperbolic angle of one hyp AOP, encloses an area AOP of one-half, or the same as the area AOP of the corresponding circular angle of Fig. 38. It should be observed here that although one circular radian subtends an angle AOP of 57° 17′ 44.8″, one hyperbolic radian subtends a circular angle AOP of 37° 17′ 33.67″ (0.65087 circular radian).

In the same way as for the circle the hyperbolic angle may be expressed in radians as,

$$\frac{\text{Length of arc}}{\rho} \text{ or } \frac{2 \times \text{area}}{(\text{radius})^2}$$

where ρ = the integrated mean radius from O to AP. As an illustration, the length of the arc AP, Fig. 40 is 1.3167 and the mean integrated radius to arc AP is 1.3167.

*A "hyperbolic angle," in the sense above described, is not the opening between two lines intersecting in a plane, but a quantity otherwise analogous to a circular angle and the argument x of the function sinh x, cosh x, tanh x, etc. The use of the term hyperbolic angle can only be justified by its convenience of anology.

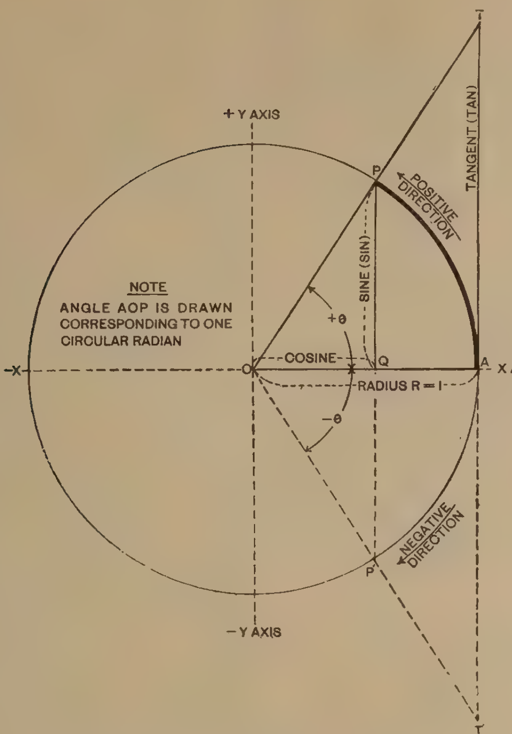


Fig. 38.—Real circular angles.
$X^2 + Y^2 = 1.$

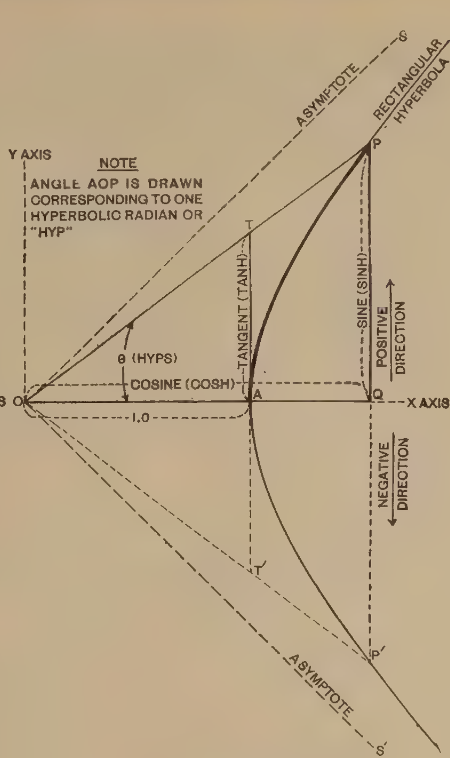


Fig. 40.—Real hyperbolic angles.
$X^2 - Y^2 = 1.$

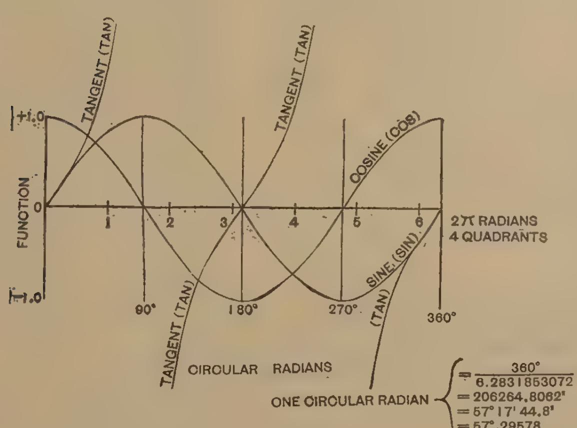


Fig. 39.—Graphs of circular functions.

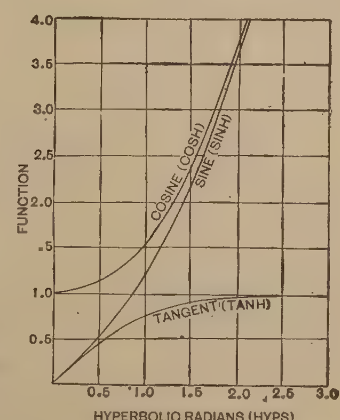


Fig. 41.—Graphs of hyperbolic functions.

Hyperbolic functions, distinguished from circular functions by the letter h affixed, are obtained as follows,

$$\text{Hyperbolic angle } \theta = \frac{\text{Length of arc } AP}{\text{Length of mean radius}} \text{ radians.}$$

$$\text{Cosh } \theta = \frac{X}{OA}$$

$$\text{Sinh } \theta = \frac{Y}{OA}$$

$$\text{Tanh } \theta = \frac{Y}{X}$$

The variations in hyperbolic functions are indicated graphically in Fig. 41 for hyperbolic angles up to approximately 2.0 hyps for the sine and cosine and up to 3.0 hyps for the tangent.

Hyperbolic functions have no true period, but adding a $2\pi j$ to the hyperbolic angle does not change the values of the functions, hence these functions have an imaginary period of $2\pi j$.

Circular functions can be used to express the phase relations of current and voltage, but not the magnitude, or size, whereas hyperbolic functions, continually increasing or decreasing, can be used to express the magnitude of current in a long circuit.

In Fig. 42 is shown a circular angle corresponding to one circular radian divided into five equal parts, each

of 0.2 radian. Assuming unity radius, each of the arcs will have a constant length of 0.2 and a constant mean radius of 1.0. In Fig. 42 is shown a hyperbolic angle corresponding to one hyperbolic radian divided into five equal hyperbolic angles each of 0.2 hyperbolic radian. In this case the length of the arcs corresponding to each subdivision increases as the hyperbolic angle increases. The lengths of the corresponding integrated mean radii vectors also increase with the angle. By dividing the length of the arc of any of the five subdivisions by the length of the mean radius for that subdivision it will be seen that each subdivision represents 0.2 hyps.

From the above it will be evident that in radian measure, the magnitudes of circular and hyperbolic angles are similarly defined with reference to the area of circular and hyperbolic sectors.

COMPLEX ANGLES AND THEIR FUNCTIONS

A complex angle is one which is associated with both a hyperbolic and a circular sector. If the complex angle is hyperbolic, its real part relates to a hyperbolic and its imaginary to a circular sector. On the other hand, if the complex angle is circular, its real part relates to a circular and its imaginary part to a hyperbolic sector. Complex hyperbolic trigonometry and complex circular trigonometry thus unite in a common geometrical relationship.

In the following treatment for the solution of transmission circuits by hyperbolic functions, only hyperbolic complex angles will enter into the solution. Such a complex angle will then consist of a combination of a "real" hyperbolic sector and a so-called "imaginary" or circular sector. The circular sector will occupy a plane inclined at an angle to the plane of the hyperbolic sector. In other words, the complex angle will be of the three-dimensional order. The construction of such a complex angle may be difficult to follow if viewed only from one direction. In order to illustrate the form that a complex angle takes, the construction for the cosine of a hyperbolic complex angle is illustrated by Fig. 43.

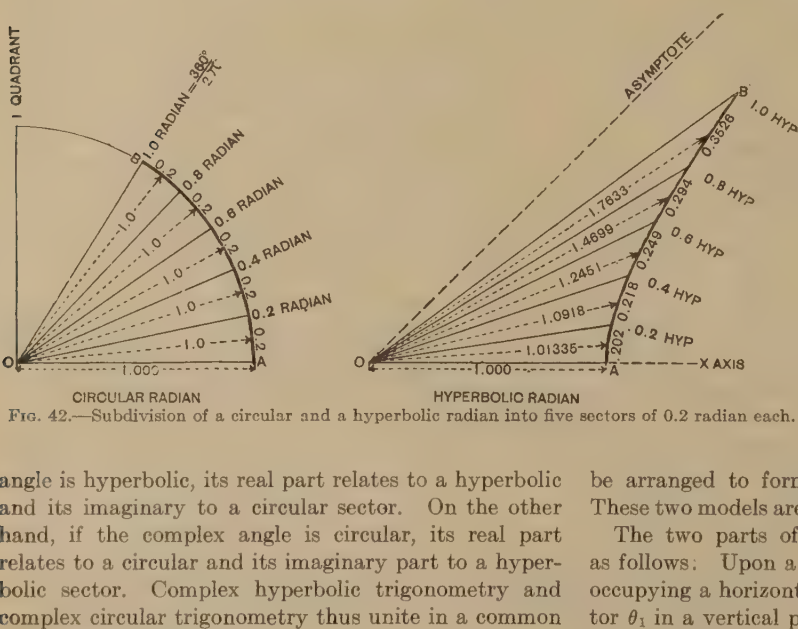


Fig. 42.—Subdivision of a circular and a hyperbolic radian into five sectors of 0.2 radian each.

CONSTRUCTION FOR COSH θ

The construction, Fig. 43, assumes that the real part, that is the hyperbolic sector subtends an angle of one hyperbolic radian and the imaginary part, that is the circular sector, subtends an angle of one circular radian. This hyperbolic complex angle has therefore a numerical value of $1 + j1$ hyperbolic radian. These numerical values embrace sectors sufficiently large for the purpose of clear illustration. The actual construction for obtaining the complex function cosh $(\theta_1 + j\theta_2)$ = cosh ($1 + j1$ hyperbolic radians) may be carried out as follows:

On a piece of stiff card board lay out to a suitable scale the hyperbolic sector $\theta_1 = EOC$, equal to one hyp as shown in the upper left hand corner of Fig. 43. This may readily be plotted by the aid of a table of real hyperbolic functions for say each one-tenth of a hyp up to and including one hyp. These are then plotted on the cardboard and joined with a curved line thus forming the arc EC of Fig. 43. The ends of the arc are then joined with O by straight lines. The real part of this hyperbolic complex angle is then cut out of the cardboard.

The circular part $j\theta_2$ of this complex angle is traced upon the cardboard as follows: With radius equal to cosh θ_1 (to the same scale as used when tracing the hyperbolic sector θ_1) draw the arc DOF of a length such that the angle DOF is 57° 17′ 44.8″ (one circular radian). Join the ends of the arc to O with straight lines. The circular part $j\theta_2$ of this complex-angle is now cut out of the piece of cardboard. This gives models of the two parts of the complex angle which may be arranged to form the complex angle $1 + j1$ hyps. These two models are shown at the top of Fig. 43.

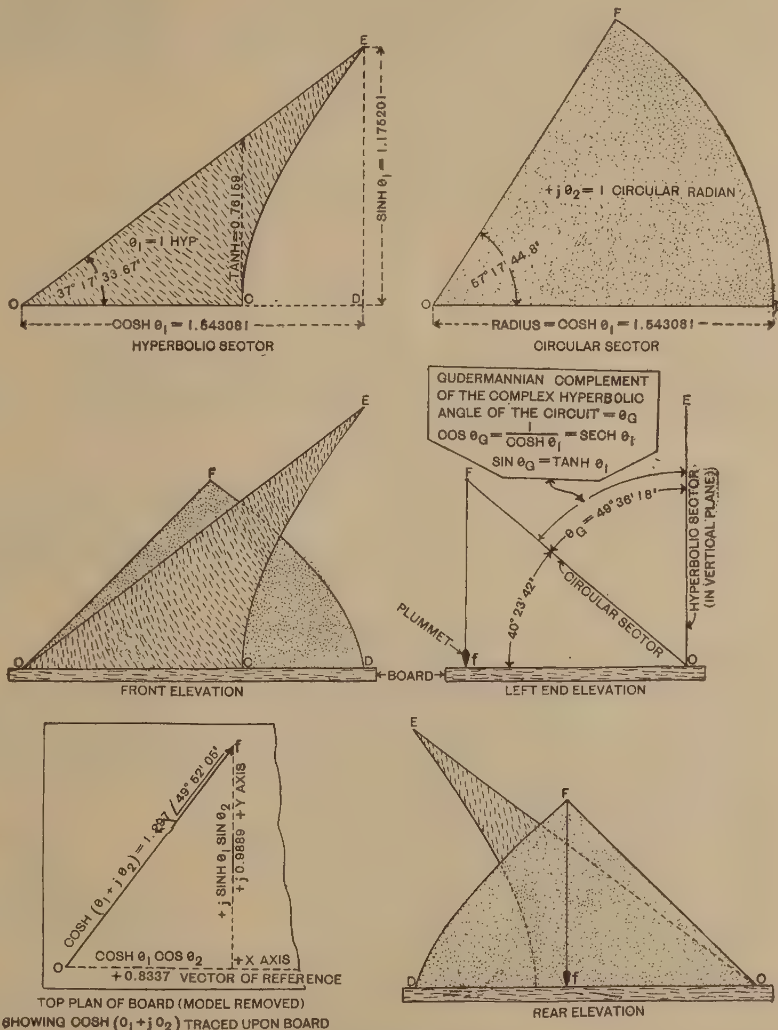
The two parts of the complex angle are arranged as follows: Upon a drawing board or any flat surface occupying a horizontal plane, place the hyperbolic sector θ_1 in a vertical position. The plane of this hyperbolic sector will then be at right angles to the plane of the drawing board. The circular sector $j\theta_2$ is now placed in a vertical position just back of the hyperbolic sector. The toes O of each sector will then coincide, as well as the line OD of the circular sector with the line OC of the hyperbolic sector. The top of the circular sector is now turned back so that the plane of the circular sector lies at an angle with the vertical plane occupied by the hyperbolic sector. This displacement angle between the planes of the two sectors is known as the "gudermannian complement" of the hyperbolic angle θ. It will be referred to as θ_g. The front elevation of Fig. 43 illustrates how these two sectors would appear when viewed from the front. To the right of this illustration is shown how these two sectors would

appear when viewed from the left hand end of the model. The displacement angle θ_g has a value for this particular complex angle of 49° 36′ 18″. This numerical value is determined by virtue of the fact that this displacement angle has a cosine of $1/\cosh\theta_1 = 1/1.543081 = 0.64805$ or cosine of $\theta_g = \text{sech}\,\theta_1 = 0.64805$. It has a sine of $\tanh\theta_1 = 0.76159$.

The ang'e whose cosine is 0.64805 and whose sine is 0.76159 is 49° 36′ 18″. Thus the top part of the circular sector of this complex angle is moved in the forward direction through an angle of 49° 36′ 18″ so that the plane of the circular sector assumes an angle of 90° 00′ 00″ —49° 36′ 18″ = 40° 23′ 42″ with the horizontal plane of the drawing board. From the end of the circular sector (point F) thus inclined, a plummet may be suspended until it meets the horizontal plane of the drawing board at the point f of the illustration. In other words, the point F is projected orthogonally onto the horizontal plane of the drawing board.

A top view of the drawing board, with the model removed, is illustrated in the lower left hand corner of Fig. 43. The line OF ($1.297/\underline{49°\ 52'\ 05''}$) traced upon the horizontal drawing board, is a vector representing the complex cosine of the complex angle $\theta_1 + j\theta_2 = 1 + j1$ hyperbolic radians. This complex cosine has rectangular coordinates of $+0.8337$ and $+j0.9889$.

At the bottom of Fig. 43 is given the mathematical expression for the exact solution for the cosine of a complex hyperbolic angle following the construction illustrated. There are numerous other mathematical equations with their equivalent geometrical constructions which will produce the same values for the cosine, but the above is probably as easy to follow as any, and will therefore be used exclusively hereafter.



MATHEMATICAL SOLUTION

$$\cosh(\theta_1 + j\theta_2) = (\cosh\theta_1\cos\theta_2 + j\sinh\theta_1\sin\theta_2)$$

$$\begin{array}{ll} \log\cosh\theta_1 = 0.188{,}389 & \log\sinh\theta_1 = 0.070{,}112 \\ \log\cos\theta_2 = \bar{1}.732{,}636 & \log\sin\theta_2 = \bar{1}.925{,}039 \\ \hline \bar{1}.921{,}025 & \bar{1}.995{,}151 \end{array}$$

$$\cosh(\theta_1 + j\theta_2) = 0.8337 + j0.9889$$
$$= 1.297\,\underline{/49°\ 52'\ 05''}$$

FIG. 43.—Graphic construction for the hyperbolic cosine of the complex angle. $\theta_1 + j\theta_2 = 1 + j1$ Hyperbolic radians.

CONSTRUCTION FOR SINH θ

The construction for the sine of the complex hyperbolic angle $1 + j1$ is indicated in Fig. 44. In this case the same construction may be used for obtaining the sinh as for determining the cosh of the complex angle with the following two exceptions.

The circular sector is made one quadrant (90°) larger. In other words the angle DOF' is 90° + 57° 17′ 44.8″ or 147° 17′ 44.8″ as indicated by Fig. 44. It occupies the same plane as when determining the cosh of the angle but is simply extended in the forward direction through one quadrant, as indicated by the dotted lines of Fig. 44. The plummet is again suspended, this time from point F' upon the horizontal board, which it meets at point f'. The other difference is that the sine OF' is read off from the Y axis as the vector of reference in place of the X axis as in the case

of the cosine. Thus the circular sector has been carried forward through an angle of 90 degrees in the circular angle plane and the vector of reference has been advanced 90 degrees in the horizontal plane of reference. The sine of this angle is $1.446\underline{/63° 56' 37''}$ and has rectangular components of $0.6349 + j1.2985$. The mathematical expression for exact solution for the sine of a complex angle likewise accompanies the illustrated geometrical construction.

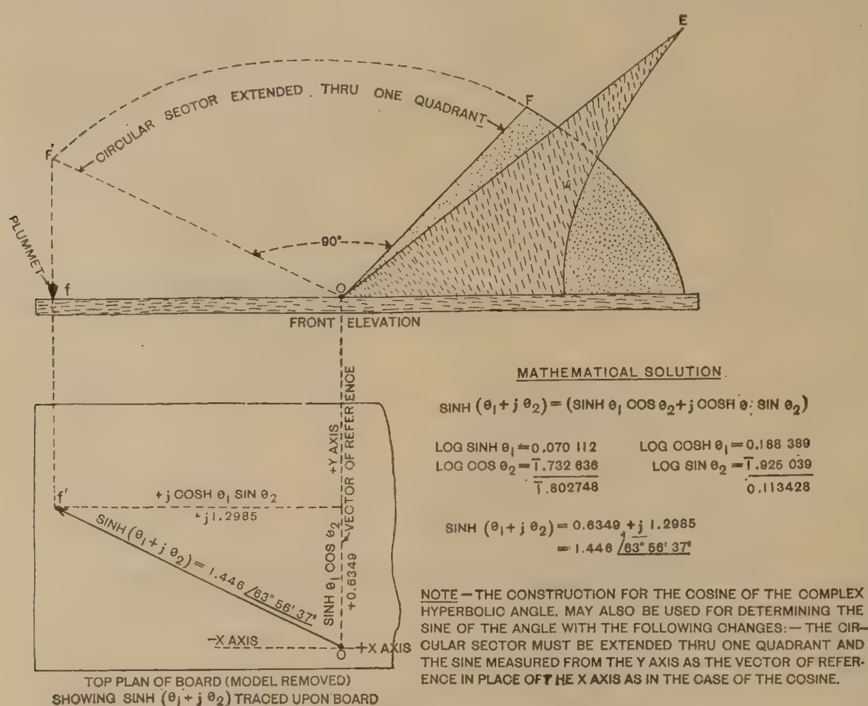


Fig. 44.—Graphical construction for the hyperbolic sine of the complex angle. $\theta_1 + j\theta_2 = 1 + j1$ hyperbolic radians.

MODEL FOR ILLUSTRATING THE FUNCTIONS OF A COMPLEX ANGLE

Dr. Kennelly has recently constructed a model* for illustrating complex angles and for obtaining approximate values for the functions of such angles. Drawings made from photographs of this model are shown in Figs. 45, 46 and 47. The construction of a complex angle as above described is that employed by Dr. Kennelly in building his model. Since the model is applicable to tracing out numerous complex angles, it may seem a little difficult at the start. It was therefore thought desirable to precede the description of the model which is applicable to the solution of so many angles with a similar solution of a single definite complex angle. With the procedure for the solution, as given above, for cosh and sinh of $1 + j1$ hyperbolic radians in mind, it is believed that Dr. Kennelly's description of the model and its application in determining the cosh and sinh of complex angles may be followed as given in the following paragraphs.

* This model was described in a paper read by him at a meeting of the American Academy of Arts and Sciences in April 1919.

DESCRIPTION OF MODEL

In this model, the cosine or sine of a complex angle, either hyperbolic or circular, can be produced, by two successive orthogonal projections onto the XY plane, one projection being made from a rectangular hyperbola, and the other projection being then made from a particular circle definitely selected from among a theoretically infinite number of such circles, all concentric at the origin O, which circles, however, are not coplanar. The selection of the particular circle is determined by the foot of the projection from the hyperbola. This effects a geometrical process which is easily apprehended and visualized; so that once it has been realized by the student, the three-dimensional artifice is rendered superfluous, and he can roughly trace out a complex sine or cosine on an imaginary drawing board, with his eyes closed. The model, however, possesses certain interesting geometrical properties as a three-dimensional structure.

A drawing made from a photograph of the model is shown in Fig. 45. On an ordinary horizontal drawing board 53.5 by 31.8 cm., is a horizontal rod AB, which merely serves to support the various brass-wire semicircles, and a semihyperbola, in their proper positions. The axis of AB in the XY plane, on the upper surface of the board, is a line of symmetry for the structure, which, if complete, would be formed by full circles and a complete hyperbola. For convenience, however, only the half of the structure above the XY plane is presented, the omission of the lower half being readily compensated for in the imagination.

The eight wire semicircles are formed with the following respective radii, in decimenters: 1.0, 1.020 . . ., 1.081 . . ., 1.185 . . ., 1.337 . . ., 1.543 . . ., 1.810 . . ., and 2.150 . . ., which are the respective cosines of 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, and 1.4 hyperbolic radians, according to ordinary tables of real hyperbolic functions. These successive semicircles therefore have radii equal to the cosines of successively

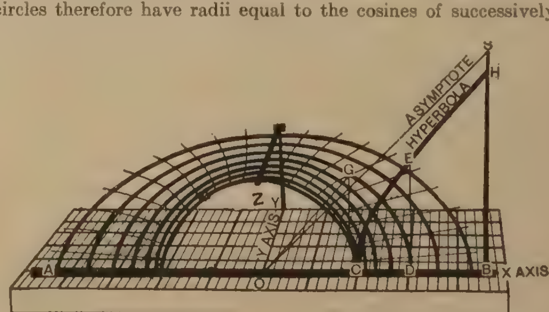


Fig. 45.—Drawing from a photograph of a geometrical model. For the orthogonal projection of the sines and cosines of complex angles. This model was developed by A. E. Kennelly.

increasing real hyperbolic angles θ_1, by steps of 0.2, from 0 to 1.4 hyperbolic radians, inclusive. All of these semicircles have their common center at the origin O, in the plane XOY, of the

drawing board. The planes of the semicircles are, however, displaced. The smallest circle of unit radius (1 dm.), occupies the vertical plane XOZ, in which also lies the rectangular semi-hyperbola XOH. Angular distances corresponding to 0.2, 0.4, . . . 1.4 hyperbolic radians, are marked off along this hyperbola at successive corresponding intervals of 0.2. The cosines of these angles, as obtainable projectively on the OX axis are marked off between C and B along the brass supporting bar, and at each mark, a semicircle rises from the XY plane, at a certain angle θ_g with the vertical XOZ plane. This displacement angle is determined by the relation,

$$\cos \theta_g = \frac{1}{\cosh \theta_1} = \operatorname{sech} \theta_1$$

Where θ_1 is the particular hyperbolic angle selected. This means, as is well known, that the displacement angle θ_g between the plane of any semicircle and the vertical plane ZOX is equal to the gudermannian of the hyperbolic angle θ_1.

The model is, of course, only a skeleton structure of eight stages. If it could be completely developed, the number of semicircles would become infinite, and they would form a smooth continuous surface in three dimensions. Along the midplane ZOY, all of these circles would have the same level, raised 1 dm. above the horizontal drawing board plane of reference XOY. The circles would increase in radius without limit, and would cover the entire XOY plane to infinity, the hyperbola extending likewise to infinity toward its asymptote OS, in the XOZ plane. The actual model is thus the skeleton of the upper central sheet of the entire theoretical surface, near the origin.

The semicircles are also marked off in uniform steps of circular angle. Each step is taken, for convenience, as nine degrees, or one-tenth of a quadrant. Corresponding angular steps on all of the eight semicircles are connected by thin wires, as shown in the illustrations.

A front elevation of the model, taken from a point on the OY axis—15 units from O, is given in Fig. 46. It will be seen that any tie wire, connecting corresponding circular angular points

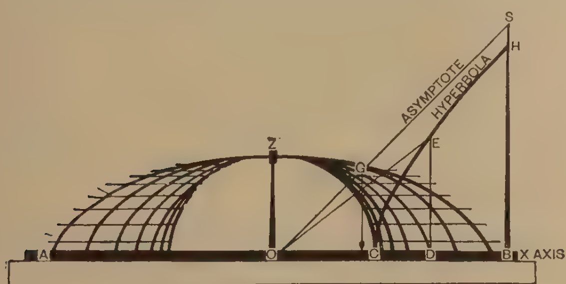


FIG. 46.—Front elevation of model.
From a point on the OY axis, 15 units from O.

on the semicircles, is level, and lies at a constant height $\sin \theta_2$ decimeters above the drawing board. That is, the tie wire that connects all points of circular angle θ_2, measured from OX positively towards OY, lies at the uniform height $\sin \theta_2$ decimeters above the drawing board.

A plan view of the model, taken from a point on the OZ axis, +15 units above O, is given in Fig. 47. It will be seen that each semicircle forms an ellipse, when projected on the base plane XOY. The semi-major axis of this ellipse has length $\cosh \theta_1$, where θ_1 is the hyperbolic angle corresponding to that semicircle. The semi-minor axis is,

$$\cosh \theta_1 \sin \theta_g = \cosh \theta_1 \tanh \theta_1 = \sinh \theta_1$$

from the well known relation that exists between a hyperbolic angle and its gudermannian circular angle; namely,

$$\sin \theta_g = \tanh \theta_1$$

All of these ellipses have the same center of reference O. Any such system, having semi-major axes $\cosh \theta_1$, and semi-minor axes $\sinh \theta_1$, are well known to be confocal, and the foci must lie at the points +1 and −1 in the XOY plane, or the points in which the innermost circle cuts that plane.

Procedure for Projecting Cosh ($\pm\theta_1 \pm j\theta_2$)

Thus premised, the process of finding the cosine of a complex hyperbolic angle $\theta_1 + j\theta_2$; that is, the process of finding cosh ($\theta_1 + j\theta_2$) is as follows:

Find the arc CE, Fig. 45, from $C = +1$ along the rectangular hyperbola CEH, which subtends θ_1 radians. The hyperbolic sector comprised between the radius, OC, the hyperbolic arc, and the radius vector OE, on this arc from the origin O, will then include $\theta_1/2$ sq. dm. of area. Drop a vertical perpendicular from E onto OX. It will mark off a horizontal distance OD equal to $\cosh \theta_1$. Proceed along the circle which rises at D, in a positive or counterclockwise direction, through θ_2 circular radians, thus reaching on that circle a point G whose elevation above the drawing board is $\sin \theta_2$ decimeters. The area enclosed by a radius vector from the origin O on the circle, followed between the axis OC and the circular curve, will be $\theta_2/2 \cosh^2\theta_1$ sq. dms.

From G, drop a vertical plummet, as in Fig. 46, on to the drawing board. In other words, project G orthogonally on the plane XOY. Let g be the point on the drawing board at which the plummet from G touches the surface. Then it is easily seen that Og on the drawing board is the required magnitude and direction of cosh ($\theta_1 + j\theta_2$), in decimeters, with reference to OX as the initial line in the plane XOY. It may be read off either in rectangular coordinates along axes OX and OY on a tracing cloth surface as shown in Fig. 47, or in polar coordinates printed on a sheet seen through the tracing cloth.

If the circular angle θ_2, *i.e.*, the imaginary hyperbolic angle $j\theta_2$, lies between π and 2π radians, (in quadrants 3 and 4), the point G will lie on the under side of the plane XOY, and the projection onto g in that plane must be made upwards, instead of downwards.

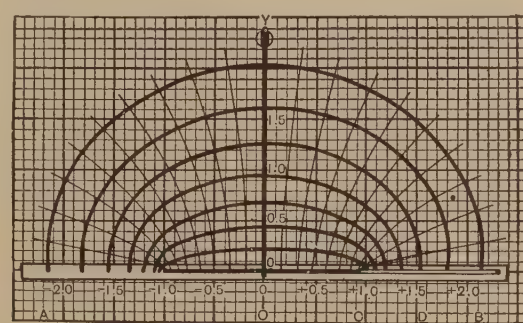


FIG. 47.—Plan view of model.
From a point on the OZ axis, 15 units from O.

If the hyperbolic angle whose cosine is required has a negative imaginary component, according to the expression cosh ($\theta_1 - j\theta_2$), then starting from the projected point D, we must trace out the circular angle in the negative or clockwise direction, as viewed from the front of the model.

If the real part of the hyperbolic angle is negative, according to the expression cosh ($-\theta_1 \pm j\theta_2$); then since cosh $-(\theta_1 \pm j\theta_2)$ = cosh ($\theta_1 \pm j\theta_2$), we proceed as in the case of a positive real component, but with a change in the sign of the imaginary component.

The operation of tracing cosh ($\pm\theta_1 \pm j\theta_2$) on the XY plane, thus calls for two successive orthogonal projections onto that plane; namely (1) the projection corresponding to cosh ($\pm\theta_1$) as though $j\theta_2$ did not exist, and then (2), the projection corresponding to $\cosh j\theta_2 = \cos \theta_2$ independently of θ_1, except that the radius of the circle, and its plane, are both conditioned by the magnitude of θ_1.

If we trace the locus of cosh ($\theta_1 \pm j\theta_2$), where θ_1 is held constant, it is evident from Fig. 47 that we shall remain on one circle, which projects into the same corresponding ellipse on the XY plane. That is, the locus of cosh ($\theta_1 \pm j\theta_2$) with θ_1

held constant, is an ellipse, whose semi major and minor diameters are cosh θ_1 and sinh θ_1 respectively. If, on the other hand, we trace cosh $(\pm\theta_1 + j\theta_2)$ with θ_2 held constant, we shall run over a certain tie wire bridging all the circles in the model, which tie wire is sin θ_2 dm. above the board, and its projection on the board, in the plane XY of projection, is part of a hyperbola.

PROCEDURE FOR SINH $(\theta_1 + j\theta_2)$

It would be readily possible to produce a modification of this model here described, which would enable the sine of a complex angle to be projected on the XY plane following constructions already referred to. The transition to a new model for sines is, however, unnecessary. It suffices to use the cosine model here described in a slightly different way. One has only to recall that

$$\sinh\theta = -j\cosh\left(\theta + j\frac{\pi}{2}\right)$$

or

$$\sinh(\theta_1 + j\theta_2) = -j\cosh\left[\theta_1 + j\left(\theta_2 + \frac{\pi}{2}\right)\right]$$

Consequently, in order to find the sine of a complex hyperbolic angle, we proceed on the model as though we sought the cosine of the same angle, increased by $\pi/2$ radians or one quadrant, in the imaginary or circular component. We then operate with $-j$ on the plane vector so obtained; *i.e.*, we rotate it through one quadrant in the XY plane and in the clockwise direction. An equivalent step is, however, to rotate the X and Y axes of reference in that plane through one quadrant in the reverse or positive direction. That is, we may omit the $-j$ operation, if, in dealing with sine projections, we treat OY as an OX axis, and $-OX$ as an OY axis, or read off the projections on the XY plane to the $-YOY$ axis as initial line.

The only difference, therefore, between projecting the cosine and the sine of a complex hyperbolic angle in the model, is that in the latter case the circular component is increased by one quadrant and the projected plane vector is read off to the OY reference axis as initial line. The model thus gives the projection of either cosh $(\pm\theta_1 \pm j\theta_2)$ or sinh $(\pm\theta_1 \pm j\theta_2)$ within the limits of $+1.4$ and -1.4 for θ_1, and for θ_2 between the limits $+\infty$ and $-\infty$. For accurate numerical work, reference would, of course, be made to the charts and tables of such functions already published, and which enable such functions to be obtained either directly or by interpolation, for all ordinary values of θ_1 and θ_2.

PERFORMANCE

As stated in the discussion of the convergent series solution, the performance of an electric circuit is completely determined by its physical characteristics; resistance, reactance, conductance and capacitance and the impressed frequency. These five quantities are accurately and fully accounted for in the two complex quantities.

$$\text{Impedance } Z = R + jX$$
$$\text{Admittance } Y = G + jB$$

Having determined the numerical values for these two complex quantities, no further consideration need be given to the physical quantities of the circuit or to the frequency.

In the hyperbolic theory the circuit is said to subtend a certain complex angle, $\theta = \sqrt{ZY}$. This quantity represents in a sense the electrical length of the circuit. The numerical value of this angle θ is expressed in hyperbolic radians. If the circuit is very long electrically the numerical value of the angle will be comparatively large. Conversely, if the circuit is electrically short, it will be comparatively small. The numerical value of the angle θ is, therefore, a measure of the electrical length of the circuit and an indication of how much distortion in the distribution of voltage and current is to be expected as an effect of the capacitance and leakance of the circuit.

In order to give an idea of the extent of the variation in the angle θ and its functions cosh θ and sinh θ for power transmission circuits of various lengths corresponding to 25 and 60-cycle frequencies approximate values have been calculated, as shown in Table O.

This tabulation indicates that for circuits of from 100 to 500 miles in length, operated at frequencies of 25 and 60 cycles, the complex hyperbolic angle of the circuit (which is a plane-vector quantity) has a maximum modulus, or size of 0.41 for 25 cycles and of 1.05 for 60 cycles. It has an argument or slope, lying between 70 and 78 degrees for 25 cycles and between 80 and 85 degrees for 60 cycles.

In the convergent series solution, the three so-called auxiliary constants A, B and C determine the performance of the circuit. These three auxiliary constants are

TABLE O.—GENERAL EFFECT OF DISTANCE AND FREQUENCY UPON THE COMPLEX HYPERBOLIC ANGLE AND ITS FUNCTIONS

Length of circuit (miles)	Z	Y	ZY	$\theta = \sqrt{ZY}$	Cosh θ	Sinh θ
			25 cycles			
100	$43.3\angle 50^\circ$	$0.000230\angle 90^\circ$	$0.00996\angle 140^\circ$	$0.10\angle 70^\circ$	$0.99\angle 0.2^\circ$	$0.10\angle 70^\circ$
200	$80.6\angle 60^\circ$	$0.000430\angle 90^\circ$	$0.03466\angle 150^\circ$	$0.19\angle 75^\circ$	$0.98\angle 0.5^\circ$	$0.19\angle 75^\circ$
300	$109\angle 65^\circ$	$0.000670\angle 90^\circ$	$0.07303\angle 155^\circ$	$0.27\angle 77^\circ$	$0.96\angle 0.9^\circ$	$0.27\angle 77^\circ$
400	$143\angle 66^\circ$	$0.000900\angle 90^\circ$	$0.12870\angle 156^\circ$	$0.36\angle 78^\circ$	$0.94\angle 1.5^\circ$	$0.35\angle 78^\circ$
500	$156\angle 67^\circ$	$0.001100\angle 90^\circ$	$0.17160\angle 157^\circ$	$0.41\angle 78^\circ$	$0.91\angle 2.5^\circ$	$0.39\angle 79^\circ$
			60 cycles			
100	$84.8\angle 71^\circ$	$0.000560\angle 90^\circ$	$0.04749\angle 161^\circ$	$0.22\angle 80^\circ$	$0.98\angle 0.5^\circ$	$0.22\angle 80^\circ$
200	$165\angle 76^\circ$	$0.001050\angle 90^\circ$	$0.17325\angle 166^\circ$	$0.42\angle 83^\circ$	$0.91\angle 1.3^\circ$	$0.41\angle 83^\circ$
300	$244\angle 79^\circ$	$0.001600\angle 90^\circ$	$0.39040\angle 169^\circ$	$0.63\angle 84^\circ$	$0.81\angle 2.3^\circ$	$0.60\angle 85^\circ$
400	$326\angle 80^\circ$	$0.002150\angle 90^\circ$	$0.70090\angle 170^\circ$	$0.84\angle 85^\circ$	$0.67\angle 5.6^\circ$	$0.74\angle 86^\circ$
500	$407\angle 80^\circ$	$0.002700\angle 90^\circ$	$1.09890\angle 170^\circ$	$1.05\angle 86^\circ$	$0.51\angle 9.1^\circ$	$0.87\angle 87^\circ$

These values are but roughly approximate to illustrate the general effect for certain circuits.

simply expressions for certain hyperbolic functions of the complex hyperbolic angle θ of the circuit.

Thus:

$$A = \cosh \theta$$

$$B = \sinh \theta \sqrt{\frac{Z}{Y}} = Z \frac{\sinh \theta}{\theta} = Z'$$

$$C = \sinh \theta \frac{1}{\sqrt{\frac{Z}{Y}}} = \sinh \theta \sqrt{\frac{Y}{Z}} = Y \frac{\sinh \theta}{\theta} = Y'$$

Additional Symbols

In addition to the symbols previously listed, the following will be employed in the hyperbolic treatment.

α = Linear hyperbolic angle expressed in hyps per mile. It is a complex quantity consisting of a real component α_1 and an imaginary component α_2. It is also known as the attenuation constant or the propagation constant of the circuit.

α_1 = The real component of the linear hyperbolic angle α, expressed in hyps. It is a measure of the shrinkage or loss in amplitude of the traveling wave, per unit length of line traversed.

α_2 = The imaginary component of the linear hyperbolic angle α, expressed in circular radians. It is a measure of the loss in phase angle of the traveling wave, per unit length of line traversed.

θ = The complex hyperbolic angle subtended by the entire circuit, expressed in hyps. It differs from α in that it embraces the entire circuit, whereas α embraces unit length of circuit (in this case one mile), $\theta = \alpha \times L$, where L is the length of the circuit expressed in miles.

θ_1 = The real component of the complex hyperbolic angle of the circuit expressed in hyps, and defines the shrinkage or loss in amplitude or size of a traveling wave, in traversing the whole length of the line.

θ_2 = The imaginary component of the complex hyperbolic angle of the circuit expressed in circular radians, expressing the loss in phase angle or slope of the traveling wave, in traversing the whole length of line.

ϵ = 2.7182818 which is the base of the Napierian system of logarithms. $\text{Log}_{10}\epsilon = 0.4342945$.

θ_s = Position angle at sending end.

θ_r = Position angle at receiving end.

θ_p = Position angle at point P on a circuit.

δ = Impedance load to ground or zero potential at receiving end line, in ohms at an angle.

$z_0 = \sqrt{\frac{z}{y}}$ = Surge impedance of a conductor in ohms at an angle.

$y_0 = \frac{1}{z_0} = \sqrt{\frac{Y}{Z}}$ = Surge admittance of a conductor in ohms at an angle.

DETERMINATION OF THE AUXILIARY CONSTANTS

It was shown in Chart XI how values for the auxiliary constants A, B and C may be determined mathematically by convergent series form of solution, using problem X as an example. Chart XVI gives information as to how these same auxiliary constants may be determined by the use of real hyperbolic functions.

The solution for the auxiliary constants by real hyperbolic functions is given completely for problem X in Chart XVI. Vector diagrams are given to assist in following the solution. In the solution of the auxiliary constants by convergent series, the operations were carried out by aid of rectangular co-ordinates of the complex, or vector quantities. In Chart XVI, the operations are to a large extent carried out by the aid of polar co-ordinates. In the case of convergent series, most of the operations consist of adding the various terms of the series together. As addition and subtraction of complex quantities can be most readily carried out when expressed in rectangular co-ordinates, this form of expression is used for the convergent-series solution. On the other hand, powers and roots of complex quantities are most readily obtained by polar coordinate expression. In the solution by real hyperbolic functions Chart XVI, operations for powers and roots predominate, and for this reason polar expressions have been quite generally employed. The solution by real hyperbolic functions is briefly this:

The impedance Z and the admittance Y are first set down in complex form and their product obtained. The square root of this produc gives the complex angle $\theta = \sqrt{ZY}$ of the circuit. This angle is then expressed in rectangular co-ordinates as $\theta_1 + j\,\theta_2$ for the purpose of determining the numerical value of its real part θ_1 (expressed in hyps) and in imaginary or circular part θ_2 expressed in circular radians. This circular part θ_2 is converted to degrees by multiplying by 57.29578°. The hyperbolic cosine and sine of this complex angle are next obtained by the aid of logarithms of the functions of the component parts of the hyperbolic complex angle θ. The equation for cosh θ and sinh θ is given just above the solution. With a view of eliminating the necessity of calculation of cosh θ and sinh θ, for each complex angle, Dr. Kennelly has prepared tables and charts from which these two functions (and others) may be obtained directly, thus very materially shortening the solution by hyperbolic functions. Since complex angles have two variable components $(\theta_1 + j\,\theta_2)$ tables of functions of such angles would have to be quite extensive in order that the steps for which values for the functions are given be not excessive. Although tables of functions of complex angles are not as complete as is desired they are a great help in the solution of ordinary power circuits. Functions corresponding to angles lying between the values for angles in these tables may readily be approximated by simple proportion, giving values sufficiently accurate for ordinary power transmission circuits. They have been calculated in Chart XVI for the purpose of illustrating such procedure and also as a high degree of accuracy was here desired for the purpose of illustrating the agreement of the results as obtained by different rigorous methods. Ordinarily these values would be taken from tables.

SOLUTION BY NOMINAL π METHOD

By this method, in place of considering the admittance of the circuit as being distributed (as it is in the actual circuit) it is based upon the assumption that the total conductor admittance may be lumped at two points, one half being placed at each end of the circuit.

CHART XVI—RIGOROUS SOLUTION FOR AUXILIARY CONSTANTS OF PROBLEM X BY REAL HYPERBOLIC FUNCTIONS

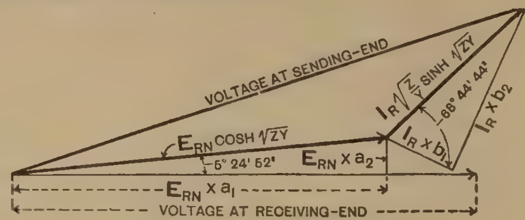
CHARACTERISTICS OF CIRCUIT

LENGTH 300 MILES. CYCLES 60.
CONDUCTORS—3 # 000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUIVALENT DELTA SPACING=12.6 FT.

LINEAR CONSTANTS OF CIRCUIT

TOTAL PER CONDUCTOR

R = 0.350 X 300 = 105 OHMS TOTAL RESISTANCE AT 25° C.
X = 0.830 X 300 = 249 OHMS TOTAL REACTANCE.
B = 5.21 X 300 X 10^{-6} = .001563 MHO TOTAL SUSCEPTANCE.
G = 0 X 300 = 0 MHO TOTAL CONDUCTANCE.
'g = (IN THIS CASE TAKEN AS ZERO).



VOLTAGE DIAGRAM

SOLUTION FOR $\theta=\sqrt{ZY}$

$$\theta_Z = \text{TAN}^{-1}\frac{X}{R} = \text{TAN}^{-1}\frac{249}{105} = 67^\circ\, 8'\, 8''$$
$$Z = R + jX = 105 + j\,249$$
$$= \sqrt{105^2 + 249^2} = 270.233$$
$$= 270.233 \;\angle 67^\circ\, 8'\, 8''$$

$$\theta_Y = \text{TAN}^{-1}\frac{B}{G} = \text{TAN}^{-1}\frac{0.001563}{0} = 90^\circ$$
$$Y = G + jB = 0 + j\,0.001563$$
$$= \sqrt{0^2 + 0.001563^2} = 0.001563$$
$$= 0.001563 \;\lfloor 90^\circ$$

$$\theta_{ZY} = \theta_Z + \theta_Y = 67^\circ\, 8'\, 8'' + 90^\circ = 157^\circ\, 8'\, 8''$$
$$ZY = 270.233 \times 0.001563 = 0.4223745$$
$$= 0.4223745 \;\backslash 157^\circ\, 8'\, 8''$$

$$\theta = \sqrt{ZY} = 0.6499035 \;\angle 78^\circ\, 34'\, 4'' \text{ HYP.}$$
$$= 0.128817 + j\,0.637009 \text{ HYP.}$$
$$= L(\alpha_1 + j\,\alpha_2)$$

$$\sqrt{\frac{Z}{Y}} = \sqrt{\frac{270.233 \;\angle 67^\circ\, 8'\, 8''}{0.001563 \;\lfloor 90^\circ}}$$
$$= \sqrt{172893 \;\backslash 22^\circ\, 51'\, 52''}$$
$$= 415.805 \;\backslash 11^\circ\, 25'\, 56''$$

WAVE LENGTH

$$\theta_2 = +j\,0.637009 \text{ HYP.}$$
$$\alpha_2 = \frac{0.637009}{300} = 0.00212336$$
$$\text{WAVE LENGTH} = \frac{2\pi}{\alpha_2} = \frac{6.2831853072}{0.00212336} = 2959 \text{ MILES}$$

SOLUTION FOR (A)

$$(A) = \text{COSH } \sqrt{ZY} = (\text{COSH } \theta_1 \text{ COS } \theta_2 + j \text{ SINH } \theta_1 \text{ SIN } \theta_2)$$
$$\theta_1 = 0.128817 \text{ HYP} \qquad \theta_2 = \frac{360^\circ}{2\pi} \times 0.637009 = 36^\circ\, 29'\, 52''$$

LOG COSH θ_1 = 0.003594	LOG SINH θ_1 = $\overline{1}$.111172
LOG COS θ_2 = $\overline{1}$.905194	LOG SIN θ_2 = $\overline{1}$.774359
LOG a_1 = $\overline{1}$.908788	LOG a_2 = $\overline{2}$.885531
a_1 = 0.81056	a_2 = 0.07683

$$0.81056 + j\,0.07683$$
$$(A) = 0.8142 \;\angle 5^\circ\, 24'\, 52''$$

SOLUTION FOR (B)

$$(B) = \sqrt{\frac{Z}{Y}} \text{ SINH } \sqrt{ZY} = \sqrt{\frac{Z}{Y}}(\text{SINH } \theta_1 \text{ COS } \theta_2 + j \text{ COSH } \theta_1 \text{ SIN } \theta_2)$$

LOG SINH θ_1 = $\overline{1}$.111172	LOG COSH θ_1 = 0.003594
LOG COS θ_2 = $\overline{1}$.905194	LOG SIN θ_2 = $\overline{1}$.774359
$\overline{1}$.016366	$\overline{1}$.777953
SINH θ_1 COS θ_2 = 0.10383	COSH θ_1 SIN θ_2 = 0.59973

$$\text{TAN}^{-1}\frac{0.59973}{0.10383} = \angle 80^\circ\, 10'\, 40''$$
$$\text{SINH } \theta_1 \text{ COS } \theta_2 + j \text{ COSH } \theta_1 \text{ SIN } \theta_2 =$$
$$= 0.10383 + j\,0.59973$$
$$= 0.60865 \;\angle 80^\circ\, 10'\, 40''$$
$$\sqrt{\frac{Z}{Y}} = 415.805 \;\backslash 11^\circ\, 25'\, 56''$$
$$= 415.805 \;\backslash 11^\circ\, 25'\, 56'' \times 0.60865 \;\angle 80^\circ\, 10'\, 40''$$
$$(B) = 253.08 \;\angle 68^\circ\, 44'\, 44''$$

SOLUTION FOR (C)

$$(C) = \frac{1}{\sqrt{\frac{Z}{Y}}} \text{ SINH } \sqrt{ZY}$$
$$= \frac{1}{415.805 \;\backslash 11^\circ\, 25'\, 56''} \times 0.60865 \;\angle 80^\circ\, 10'\, 40''$$
$$= 0.002405 \;\angle 11^\circ\, 25'\, 56'' \times 0.60865 \;\angle 80^\circ\, 10'\, 40''$$
$$(C) = 0.001464 \;\lfloor 91^\circ\, 36'\, 36''$$

As a check against possible serious errors in the calculations, the calculated values may be compared with values read from the Wilkinson Charts. The above results check exactly with those obtained by convergent series. (See Chart XI).

Such an artificial circuit is known as a "nominal π" circuit since the nominal values of impedance and admittance are ascribed to this circuit. On the above assumption, the current per conductor is the vector sum of the receiving-end load and the receiving-end condenser currents. The sending-end current is the vector sum of the conductor and the sending-end condenser currents. The performance of such a circuit may be determined either graphically or mathematically.

If the circuit is not of great electrical length, (say not over 100 miles at 60 cycles or 200 miles at 25 cycles) the performance of the corresponding nominal π circuit will not be materially different from that of the actual circuit having distributed constants which it imitates. If, however, the circuit is of great electrical length the performance of the nominal π circuit no longer closely imitates the performance of the actual circuit which it represents, owing to an error due to the lumpiness of the artificial circuit. Dr. Kennelly has shown that by making certain modifications in the linear or fundamental constants for the impedance and admittance of the nominal π circuit, the lumpiness error will vanish, so that the artificial circuit will then truly represent at the terminals the behavior under steady state operation, taking distributed admittance into account. Such a corrected artificial circuit is known as the "equivalent" π circuit, because it then becomes externally equivalent to the actual circuit, having distributed constants, in every respect.

The complex numbers which must be applied to the impedance, Z and the admittances, $Y/2$ of the nominal π circuit in order to correct these nominal values into the equivalent circuit are called the correcting factors of the nominal π circuit. The nominal values of the impedance Z and the admittances $Y/2$ of the circuit must be multiplied by these

vector correcting factors in order to convert them into the "equivalent" values; thus:

$$Z' = Z\frac{\sinh\theta}{\theta} = \text{Constant B}$$

$$\frac{Y'}{2} = \frac{Y}{2}\,\frac{\tanh\frac{\theta}{2}}{\frac{\theta}{2}}$$

Where $\theta = \sqrt{ZY}$ is the hyperbolic complex angle subtended by the circuit.

Complete tables of hyperbolic functions are not always available; then again, many engineers have a natural aversion to the use of such functions. In order to avoid these objections as well as to simplify calculations, Dr. Kennelly has charted these "correcting factors" for hyperbolic complex angles up to $\theta = 1.0$ radian in steps of 0.01 in size and 1 degree in slope. The writer is particularly indebted to Dr. Kennelly for these charts, which are reproduced herewith for the first time, as Charts XVIII, XIX, XX and XXI. It is believed that the use of these charts will greatly simplify the calculation of the performance of electric power transmission circuits by hyperbolic functions. They enable the vector values of these ratios to be read to at least three decimal places in sizes and to two decimal places in slope, and their availability makes the use of tables of hyperbolic functions unnecessary. The corrected conductor impedance Z' is the same as the familiar auxiliary constant B.

EQUIVALENT π SOLUTION FOR PROBLEM X

The solution for problem X by the equivalent π method is given in Chart XVII. At the top of the sheet are two diagrams, one a diagram for one conductor of the circuit of problem X and the other a corresponding vector diagram of the currents and the voltages at both ends. The numerical values of the angles and the quantities pertaining to problem X are placed upon the two diagrams for the purpose of assisting in following the mathematical solution.

The physical properties of the circuit are first set down, its linear constants obtained from the tables of constants and multiplied by the length of the circuit to obtain the total values per conductor. The next procedure is to calculate the hyperbolic angle θ of the circuit. To do this the impedance and the admittance of the circuit are set down as complex quantities in the form of polar co-ordinates and multiplied together by multiplying their slopes and adding their angles. The square root of the resulting vector is obtained by taking the square root of the slope and halving the angle. The result is the hyperbolic angle θ of the circuit expressed in hyps.

The ratio charts XIX and XXI are next consulted and the correcting values

$$\frac{\sinh\theta}{\theta} \text{ and } \frac{\tanh\frac{\theta}{2}}{\frac{\theta}{2}}$$

corresponding to the hyperbolic angle of the circuit read off. Having thus obtained the correcting factors corresponding to this circuit, the linear impedance Z and linear admittance Y per conductor are multiplied respectively by the sinh and the tanh correcting factors.

If the circuit under consideration is electrically short the effect of these correcting factors upon the linear constants will be small and possibly negligible but, as the circuit becomes longer, their effect becomes increasingly greater. The effect of the correcting factors for problem X is to change the liner impedance Z from $270.233\underline{/67°\ 08'\ 08''}$ to $Z' = 253.083\ \underline{/68°\ 44'\ 41''}$ and to change the linear admittance Y from $0.001563\ \underline{/90°}$ to $Y' = 0.001615512\ \underline{/89°\ 10'\ 45''}$. In other words this circuit will behave in the steady state at 60 cycles as though its conductor resistance were reduced from 105 to 91.7486 ohms and its inductive reactance reducted from 249 to 235.866 ohms. Similarly it will behave as though a non-inductive leak of 11.571 micromhos, has been applied to each condenser in shunt.

In order to illustrate the exact agreement in the results as obtained by the equivalent π method with those obtained by either the convergent series or pure hyperbolic solution, the ratio values used for this problem were calculated and not obtained graphically. The accuracy in the performance resulting from the use of ratio values taken from the charts is well within the requirements of practical power circuits. The mathematical solution for these factors is given in Fig. 48.

Having determined the corrected values for the impedance Z' and the admittance Y' which will produce exact results, the remainder of the solution may be carried out graphically as indicated by the vector diagram in the upper right hand part of Chart XVII or mathematically as indicated under this vector diagram.

EQUIVALENT T SOLUTION

Dr. Kennelly has shown that the correcting factors which convert the nominal π into the equivalent π of the conjugate smooth line, are the same as those which convert the nominal T into the equivalent T, but in inverse order; that is the correcting factors for the nominal T line are

$$Z' = Z\,\frac{\tanh\frac{\theta}{2}}{\frac{\theta}{2}}$$

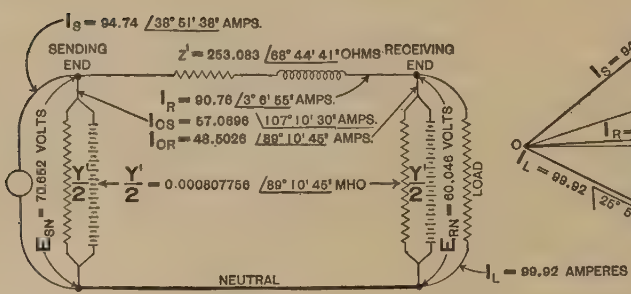
$$Y' = Y\frac{\sinh\theta}{\theta} = \text{Constant C}$$

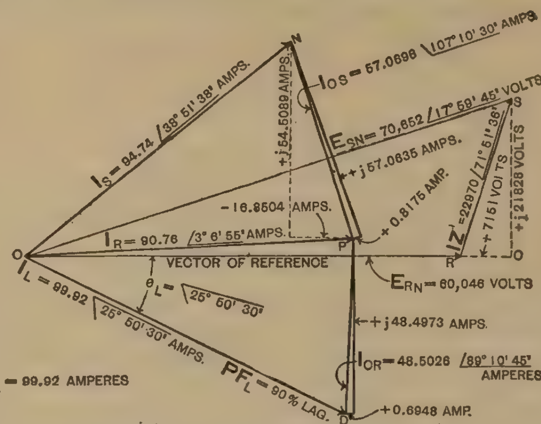
Either the equivalent π or the equivalent T solution may be used by applying the two correcting factors properly. Usually less arithmetical work will be required for the equivalent π solution.

ELECTRICAL CONDITION AT INTERMEDIATE POINTS

In the foregoing, the behavior of circuits at their terminals has been considered. In some cases it may be desirable to predetermine the voltage and the current

CHART XVII—RIGOROUS EQUIVALENT π SOLUTION OF PROBLEM X





CHARACTERISTICS OF CIRCUIT

LENGTH, 300 MILES. CYCLES, 60.
CONDUCTORS — 3 # 000 STRANDED COPPER.
SPACING OF CONDUCTORS 10 X 10 X 20 FEET.
EQUIVALENT DELTA SPACING = 12.6 FT.

LINEAR CONSTANTS OF CIRCUIT

FROM TABLES PER MILE

TABLE NO. 2. r = 0.350 OHM AT 25° C.
TABLE NO. 5. x = 0.830 OHM (BY INTERPOLATION).
TABLE NO. 10. $b = 5.21 \times 10^{-6}$ MHO (BY INTERPOLATION)
g = (IN THIS CASE TAKEN AS ZERO).

TOTAL PER CONDUCTOR

R = 0.350 X 300 = 105 OHMS TOTAL RESISTANCE.
X = 0.830 X 300 = 249 OHMS TOTAL REACTANCE.
$B = 5.21 \times 300 \times 10^{-6}$ = .001563 MHO TOTAL SUSCEPTANCE.
G = 0 X 300 = 0 MHO TOTAL CONDUCTANCE.

SOLUTION FOR HYPERBOLIC ANGLE $\theta = \sqrt{ZY}$

Z = 105 + j 249 $\qquad$ Y = 0 + j 0.001563
= 270.233 /67° 8' 8' $\qquad$ = 0.001563 /90°
$\theta = \sqrt{270.233 \angle 67° 8' 8' \times 0.001563 \angle 90°}$
$= \sqrt{0.4223745 \angle 157° 8' 8'}$
= 0.6499035 /78° 34' 4' HYP.
= 0.6499035 /78°.5678 HYP.
= 0.1288168 + j 0.6370092 HYP.

FROM DR. KENNELLY'S CHARTS

CHART XIX $\frac{\text{SINH}\,\theta}{\theta}$ = 0.9365365 /1°.6094 = 0.9365365 /1° 36' 33'

CHART XXI $\frac{\text{TANH}\,\theta/2}{\theta/2}$ = 1.033598 \0°.8206 = 1.033598 \0° 49' 15'

★ THESE VALUES WERE CALCULATED IN ORDER TO OBTAIN A HIGH DEGREE OF ACCURACY FOR THE PURPOSE OF DEMONSTRATING THE FUNDAMENTAL ACCURACY OF THIS METHOD.

CORRECTION OF LINEAR CONSTANTS

Z' = 270.233 /67° 8' 8' X 0.9365365 /1° 36' 33'
= 253.083 /68° 44' 41' (WHICH IS AUXILIARY CONSTANT (B))
= 91.7486 + j 235.866 OHMS
Y' = 0.001563 /90° X 1.033598 \0° 49' 15'
= 0.001615512 /89° 10' 45' MHO
$\frac{Y'}{2}$ = 0.000807756 /89° 10' 45'
= 0.000011571 + j 0.00080767
= 1238 \89° 10' 45' OHMS REACTANCE.

CALCULATION OF PERFORMANCE ★

PER PHASE TO NEUTRAL

$KV\text{-}A_{RN} = \frac{18,000}{3}$ = 6,000. $\qquad$ $KW_{RN} = \frac{16,200}{3}$ = 5,400.
$E_{RN} = \frac{104,000}{1.732}$ = 60,046. $\qquad$ $I_R = \frac{6,000 \times 1000}{60,046}$ = 99.92.
PF_R = 90% LAGGING.

RECEIVING-END CONDITIONS

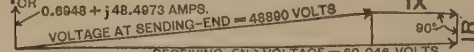
I_{OR} = 60,046 X 0.000807756 /89° 10' 45' = 48.5026 /89° 10' 45'
= 0.6948 + j 48.4973 AMP.
I_R = 99.92 (0.90 − j 0.436) + 0.6948 + j 48.4973
= 90.623 + j 4.9322 AMPS.
= 90.76 /3° 6' 55' AMPS.
PF_R = COS 3° 6' 55' = 99.85% LEADING.
KW_{OR} = 60,046 (0.6948 + j 48.4973)
= 41.72 + j 2912.069
KW_{RN} = 6000 (0.90 − j 0.436) + 41.72 + j 2912.07
= 5441.72 + j 296.07
$I_R Z'$ = 90.76 /3° 6' 55' X 253.083 /68° 44' 41'
= 22970 /71° 51' 36' VOLTS.
= 7151 + j 21,828 VOLTS

SENDING-END CONDITIONS

E_{SN} = 60,046 + 7151 + j 21828
= 67,197 + j 21,828 VOLTS
= 70,652 /17° 59' 45' VOLTS
I_{OS} = 70,652 X 0.000807756 /89° 10' 45'
= 0.8175 + j 57.0635 (TO SUPPLY END VOLTAGE)
= 57.0696 \107° 10' 30' TO VECTOR OF REFERENCE
= − 16.8504 + j 54.5089
I_S = (90.623 + j 4.9322) + (− 16.8504 + j 54.5089)
= 73.77 + 59.44 AMPS.
= 94.74 /36° 51' 38' AMPS.

PF_S = COS 36° 51' 38' − 17° 59' 45' = 93.44 % LEADING
KW_{SN} = 70.652 X 94.74 X .9344 = 6255 KW PER PHASE
LOSS = 6255 − 5400 = 855 KW PER PHASE
EFF = $\frac{5400 \times 100}{6255}$ = 86.33 %

ZERO LOAD CONDITIONS

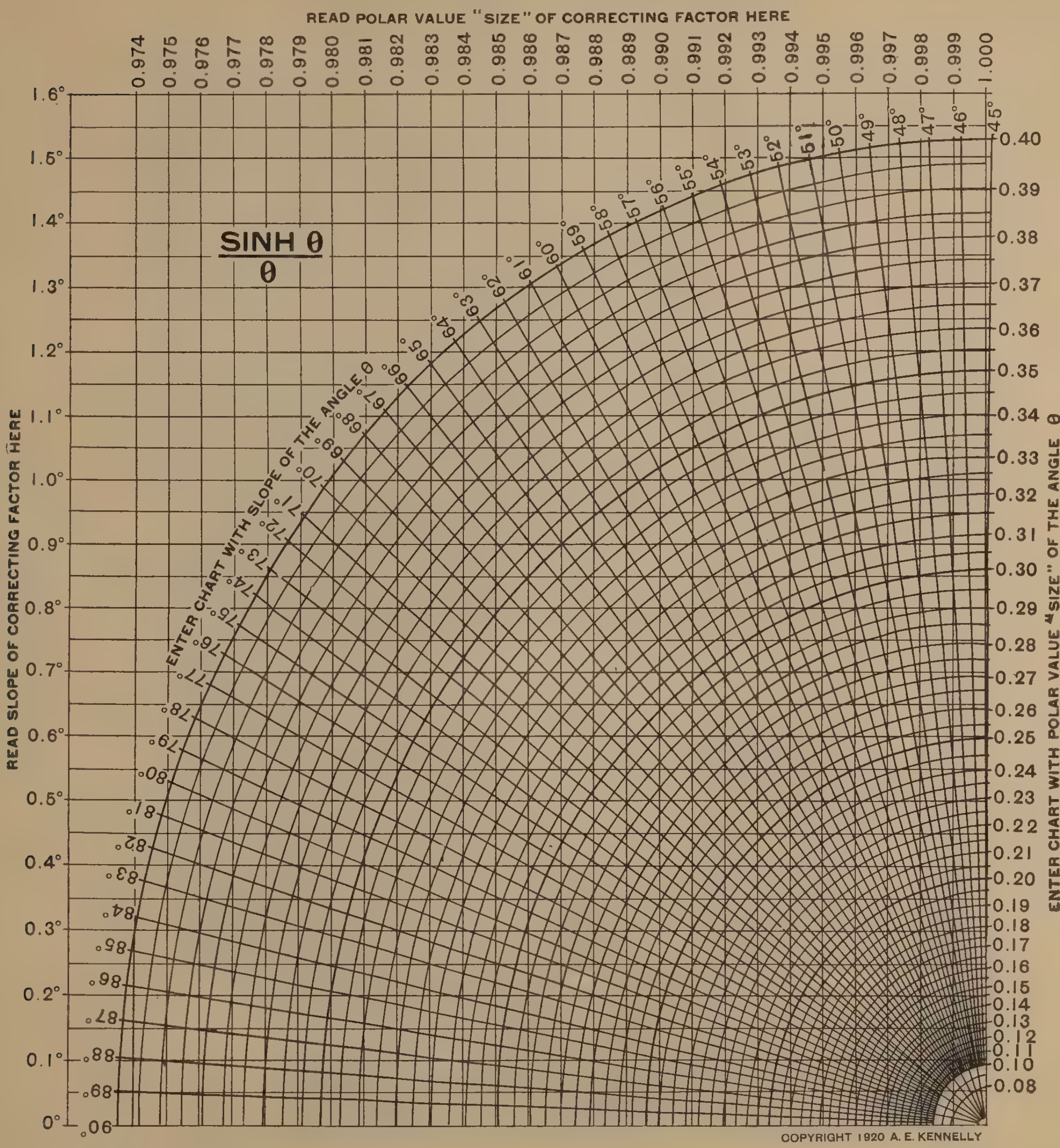


IR' = (0.6948 + j 48.4973) X 91.7486 = 64 + j 4449 VOLTS
IX' = (− 48.4973 + j 0.6948) X 235.866 = − 11438 + j 164
$IR' + IX'$ = − 11374 + 4613
E_{SNO} = (60,046 − 11373) + 4613 = 48890 VOLTS /5° 24' 51'

*The above results check with those obtained by convergent series. (See Chart XIII).

CHART XVIII—KENNELLY CHART FOR IMPEDANCE CORRECTING FACTOR

(FOR ANGLES HAVING POLAR VALUES BETWEEN 0 AND 0.40)



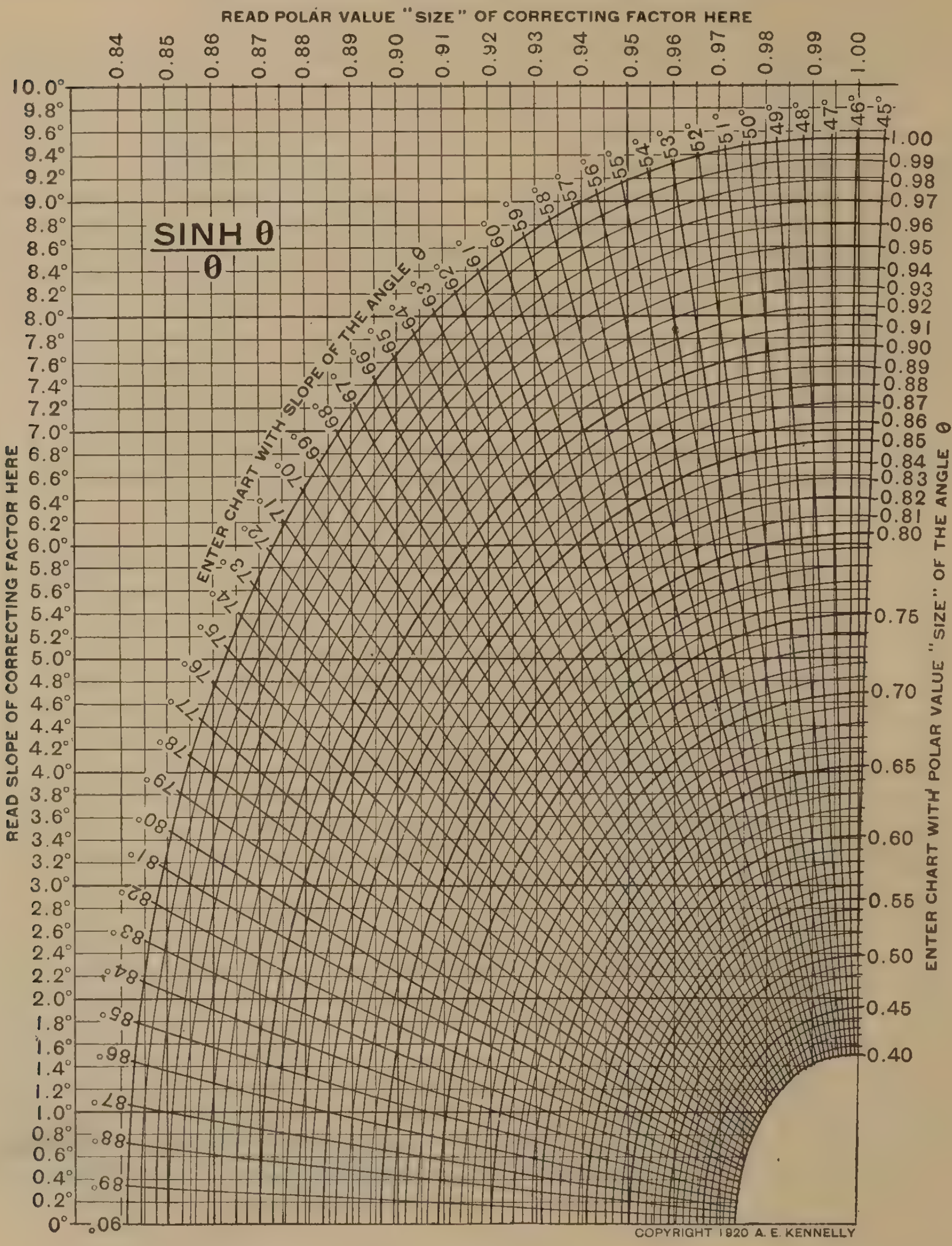
To find the vector "correcting factor" corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table *P* for rapid conversion to minutes and seconds. For example:

$$\theta = 0.3 \underline{/68^\circ}, \text{ correcting factor } = 0.9893 \underline{/0^\circ .60} = 0.9893 \underline{/0^\circ\ 36'00''}$$

$$\theta = 0.215 \underline{/80^\circ .5}, \text{ correcting factor } = 0.9927 \underline{/0^\circ .149} = 0.9927 \underline{/0^\circ\ 08'\ 56''}$$

CHART XIX—KENNELLY CHART FOR IMPEDANCE CORRECTING FACTOR

(FOR ANGLES HAVING POLAR VALUES BETWEEN 0.40 AND 1.0)



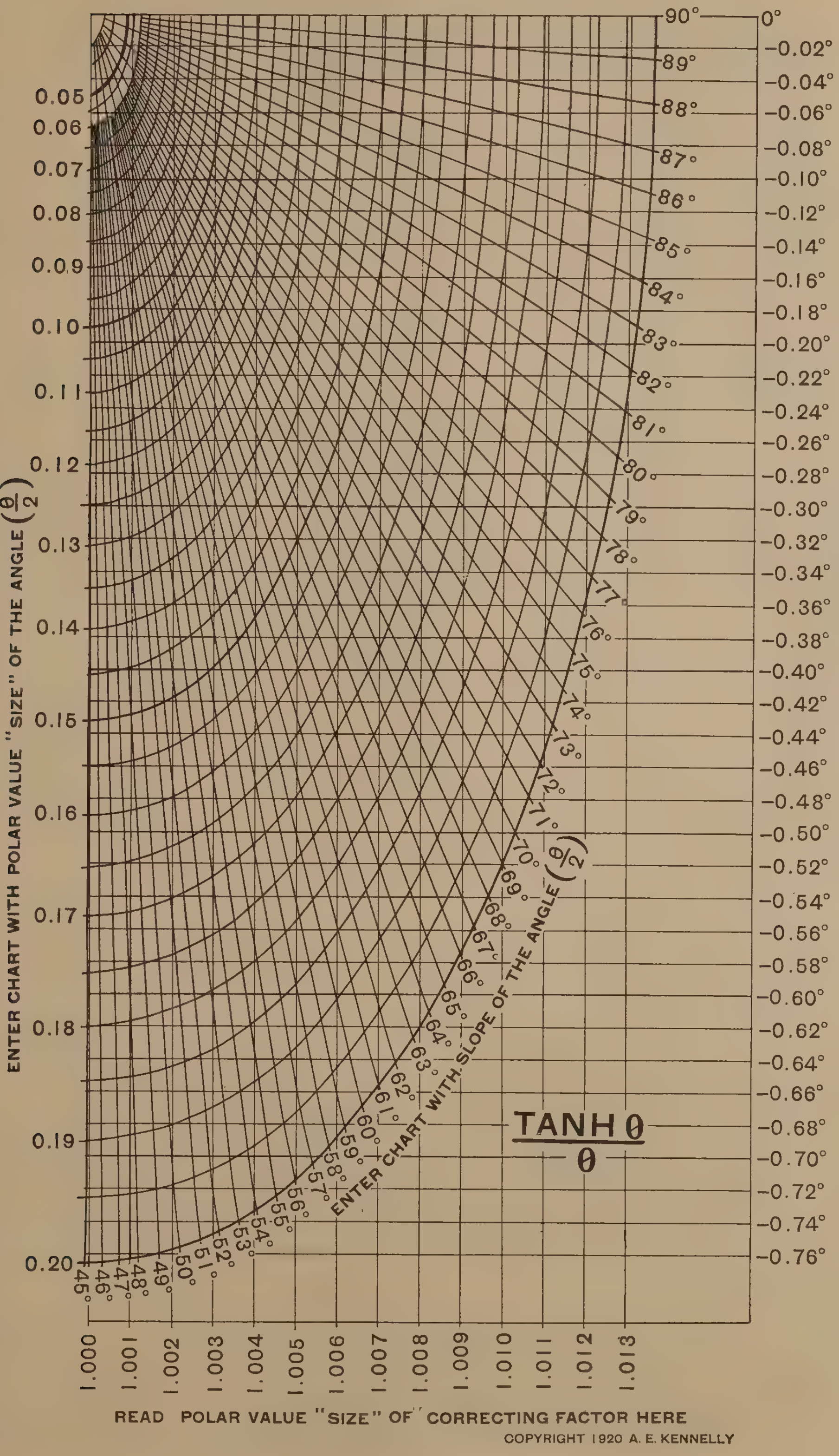
To find the vector "correcting factor" corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table *P* for rapid conversion to minutes and seconds. For example:

$\theta = 0.8 \underline{/62^\circ}$, correcting factor $= 0.943 /5^\circ .19 = 0.943 \underline{/5^\circ\ 11'\ 24''}$

$\theta = 0.6499 \underline{/78^\circ .57}$, correcting factor $= 0.9365 /1^\circ .61 = 0.9365 \underline{/1^\circ\ 36'\ 36''}$

CHART XX—KENNELLY
CHART FOR ADMITTANCE CORRECTING FACTOR

(FOR ANGLES HAVING POLAR VALUES BETWEEN 0 AND 0.20)



To find the vector correcting factor corresponding to any complex line angle θ of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The angle of the line, θ, is then divided by $2(\theta/2)$ as it is necessary to enter the admittance charts with half the angle θ. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees.

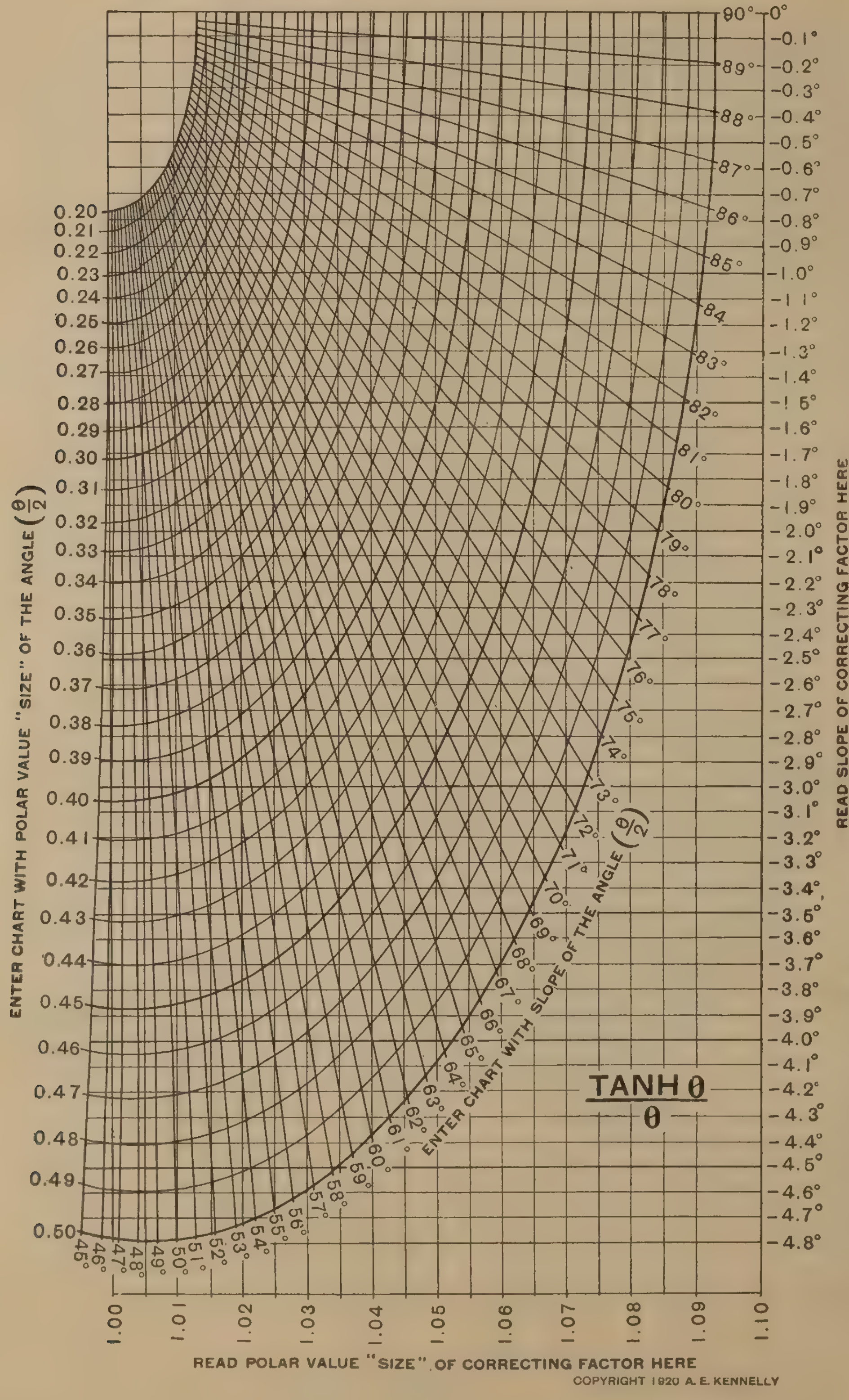
Consult Table *P* for rapid conversion to minutes and seconds. For example:

$\theta = 0.4\ \underline{/61°}$, $(\theta/2) = 0.2\ \underline{/61°}$, correcting factor $= 1.0007\ \overline{/0°.655}$
$= 1.007\ \overline{/0°\ 39'\ 18''}$

$\theta = 0.326\ \underline{/75°.5}$, $(\theta/2) = 0.163\ \underline{/75°.5}$, correcting factor $= 10{,}078\ \overline{/0°.25} = 10{,}078\ \overline{/0°\ 15'\ 00''}$

CHART XXI—KENNELLY CHART FOR ADMITTANCE CORRECTING FACTOR

(FOR ANGLES HAVING POLAR VALUES BETWEEN 0.20 AND 0.50)



To find the vector correcting factor corresponding to any complex line angle θ, of a circuit, the angle θ is expressed in polar form with the slope in fractional degrees. The angle of the line θ is then divided by $2(\theta/2)$ as it is necessary to enter the admittance charts with half the angle θ. The correcting factor as read from the chart will be in polar form with its slope in fractional degrees. Consult Table P for rapid conversion to minutes and seconds. For example:

$\theta = 0.84\ \underline{/69°}$, $\frac{\theta}{2} = 0.42\ /69°$, correcting factor $= 1.045\ \overline{/2°.4} = 1.045\ \overline{/2°\ 24'\ 00''}$

$\theta = 0.6499\ \underline{/78°.568}$, $\frac{\theta}{2} = 0.3250\ \underline{/78°.568}$, correcting factor $= 1.034\ \overline{/0°.83} = 1.034\ \overline{/0°\ 49'\ 48''}$

at points along the circuit between the terminals. This may be particularly desirable in case of circuits of great electrical length and consequently having a pronounced bend or hump in the voltage graphs representing the voltage at points along the circuit. In Fig. 21 voltage and current graphs were shown for the circuit of problem X corresponding to zero load; also load conditions. Accompanying this was stated the step-by-step method by which the current and voltage at these intermediate points had been determined. In a corresponding manner the intermediate electrical conditions may be determined by the employment of hyperbolic functions. It is usual, however, when employing hyperbolic functions for determining the voltage or the current at points along a smooth circuit, in the steady state, to take advantage of the following facts relative to the variation in current and potential from point to point in such a circuit.

The potentials of any and all points of such a circuit are as the sines and the currents as the cosines of the corresponding position angles. This means that if the position angles corresponding to two points of a smooth circuit in the steady state are known, and the voltage or the current at one of these points is also known, then the voltage or current at any other point will be directly proportional of the sine or the cosine respectively of the corresponding position angles. In a similar manner, the impedance follows the tangents, the admittance the cotangents of the angles and the volt-amperes the sines of twice the angles. Herein lies the beauty of the application of hyperbolic functions of complex angles for determining the electrical performance of electric circuits. The relationship expressed above (taken from Dr. Kennelly's "Artificial Electric Lines") are given in equation form below for ready reference:

$$\frac{E_p}{E_c} = \frac{\sinh \theta_p}{\sinh \theta_c} \text{ numeric } \angle$$

$$\frac{I_p}{I_c} = \frac{\cosh \theta_p}{\cosh \theta_c} \text{ numeric } \angle$$

$$\frac{Z_p}{Z_c} = \frac{\tanh \theta_p}{\tanh \theta_c} \text{ numeric } \angle$$

$$\frac{Y_p}{Y_c} = \frac{\coth \theta_p}{\coth \theta_c} \text{ numeric } \angle$$

$$\frac{|\text{Kv.a.}_p|}{|\text{Kv.a.}_c|} = \frac{|\sinh 2\theta_p|}{|\sinh 2\theta_c|} \text{ numeric}$$

where p and c are points along the circuit, c being some point where the electrical conditions are known, and p the point for which they are to be computed. The vertical lines enclosing the two parts of the last equation are for the purpose of indicating that the "size" of these complex quantities are referred to in this equation.

POSITION ANGLES

Reference has been made to the line as subtending a certain complex hyperbolic angle θ. Since the circuit through the load also encounters resistance and reactance, the load may be said to subtend also a certain complex hyperbolic angle, so that the receiving end of the circuit occupies an angular position θ_r. The total angle of the circuit (line and load) will be $\theta_r + \theta = \theta_s$. By similar reasoning all points lying between the receiving and sending ends of a line will occupy or assume an angular position θ_p. If that part of the linear angle θ of the line between the receiving end and the point p be designated as θ_{pr}, then the angular position of the point p will be $\theta_p = \theta_r + \theta_{pr}$. Thus, at a point in the middle of the line, the position angle will be $\theta_p = \theta_r + \theta_{pr} = \theta_r + \theta/2$.

If the line is grounded or short-circuited at the receiving end, there will be no load containing resistance and reactance, and consequently no load angle. In such case $\theta_r = 0$ and the distribution of position angles along the line will be purely a linear function of the total angle θ. In such a case $\theta_s = \theta$.

Load Conditions.—In Fig. 49 the procedure is shown which may be followed for determining by complex functions of position angles the current and the voltage vectors at points 25 miles apart along problem X circuit, under load conditions.

The procedure is first to determine the complex angle θ_r, at the receiving end resulting from the load. The mathematical determination of this load angle is tedious. Such determination is given for problem X circuit under stated load in Fig. 49. This complex angle θ_r of the load (that is the position angle at the receiving end) is such that its complex tangent equals the impedance load δ to ground, or zero potential, at the receiving end of line (ohms $\angle$) divided by the surge impedance Z_0 of a conductor (ohms $\angle$). That is,

$$\tanh \theta_r = \frac{\delta}{Z_0}$$

Since we are here interested only in the ratio between the load impedance and the surge impedance, the values may be taken either per unit length or total per conductor. Although $\tanh \theta_r$ is readily calculated, as may be seen by consulting Fig. 49, the subsequent calculation for the corresponding angle θ_r is tedious. After having calculated the $\tanh \theta_r$, the corresponding angle θ_r may be obtained with sufficient accuracy from a table of tangents of complex angles or, more readily still, from a chart of such functions.* After having determined the angle θ_r by consulting a chart of tangents of complex angles, or by mathematical calculation, as in Fig. 49, the position angles at points along the circuit may easily and readily be determined as follows:

The change in the position angle from point to point along the circuit, due to the line impedance and the line admittance is purely a linear function of the line angle θ. This is the case whether the line is grounded, loaded or free at the receiving end.

Referring to Fig. 49, the angular position of the receiving end, due to the load conditions assumed, was

* Such as that worked out by Dr. Kennelly and published by the Harvard University Press. The chart atlas referred to contains graphs of complex tangents of complex angles, and by following the chart in the reverse from the usual direction the complex angle corresponding to any complex tangent may be read off directly.

calculated to be $0.48047 + j1.06354$. It is therefore necessary to add this angle to each of the linear line angles of the various points along the line in order to obtain the position angles of the points in question. Thus the linear line angle of the middle point of the circuit is $0.0644084 + j0.3185046$ and adding to this the load angle $0.48047 + j1.06354$ gives $0.5448784 + j1.3820446$, which corresponds with the entry in the tabulation of Fig. 51 for the position angle at the middle of the circuit. In a similar manner position angles for the load assumed are readily determined for points 25 miles apart. Having determined the position angles for the various points along the circuit, the sines and the cosines corresponding to these position angles may be approximated closely from tables or charts of such complex functions, or may be calculated accurately by following the equations at the lower left hand corner of Fig. 51. Since the receiving-end voltage and current are known to be 60,046 volts and 99.92 amp. respectively, the voltage and currents at all other points of this circuit will be as the sines and cosines of the corresponding position angles. From the vector quantities that have been assigned to the voltage and current at the points along the circuit, the power-factors at these points are readily determined.

The current and voltage graphs at the bottom of Fig. 51 were plotted from values as determined by the use of functions of position angles. These check exactly with similar graphs as determined by the Wilkinson Charts and step-by-step process (See Fig. 21).

Zero Load Condition.—The procedure which may be followed for determining the position angles under zero load, their functions and the corresponding current and voltage distribution is the same as given above for load conditions and is shown in Fig. 50. In this case, however, there is no load and consequently no real part to the load angle. On the other hand the impedance of the load is infinite, that is $\delta = \infty$ so that $\theta_r = \tanh^{-1} \frac{\infty}{Z_0} = j\frac{\pi}{2}$. The effect of this supersurge impedance load at the receiving end at zero load is to cause a phase rotation of 90 degrees or one quadrant, $j\frac{\pi}{2} = j1.57080$ circular radians. Thus, at zero load, $\theta_{ro} = \left(o + j\frac{\pi}{2}\right) = o + j1.57080$ and this angle must be added to each of the linear position angles of the points along the line. With the position angles corresponding to zero load thus obtained, and assigned to the points along the circuit, the voltage will be found to follow the sines, and the current the cosines, etc. of these position angles.

POLAR DIAGRAM OF CURRENT AND VOLTAGE

In Fig. 52 are shown the polar graphs of the voltage and the current for problem X, corresponding to load, and also to zero load conditions. These polar graphs were plotted from the vector values for current and voltage as tabulated in Figs. 50 and 51 for each 25 miles of circuit.

CHOICE OF VARIOUS METHODS

Two graphical and two mathematical forms of solution for circuits of long electrical length have been described thus far. These four methods have been given for the purpose of providing a choice of procedure for the beginner. Graphical solutions are more simple and more readily performed than mathematical solutions and, if used correctly and made to a large scale, will yield results well within the limits of permissible error for power transmission circuits. There is always a possibility of error with any method, even though the solution is carefully checked. For this reason it is desirable that errors be guarded against by the use of two different forms of solution. For instance the first solution could be made by making use of the Wilkinson Charts followed by its accompanying graphical solution. The second solution could then be made by means of Dr. Kennelly's ratio Charts XVIII to XXI, followed by its accompanying graphical solution. These two methods would then yield results obtained by two entirely different routes and methods of procedure. The use of two such methods would constitute check against errors being made in either solution.

EFFECT OF HARMONIC CURRENTS AND VOLTAGES

The foregoing discussion is based upon the assumption that the fundamental wave is of sine shape and consequently free from harmonics. If harmonics of considerable magnitude are present in the fundamental wave, then it will be necessary to take their effect into account, if high accuracy is essential. In such a case there is an independent solution required of potential and current for each single frequency in turn, as though the others did not exist, and then the r.m.s. value at any point on the line is the perpendicular sum of the separate frequency values.

A detail discussion of the manner of including the effect of harmonic components in the current and voltage waves is quoted below from Dr. Kennelly's "Artificial Electric Lines."

"The ordinary complex harmonic impressed e.m.f. contains a fundamental frequency associated with multiple frequency harmonics. The nth multiple of the frequency is called the nth harmonic. The fundamental may thus be included as the first harmonic.

"In order to deal with the plural-frequency case quantitatively, it is necessary to analyze the impressed potential wave into its harmonic components. As is well known, the complete Fourier analysis of a complex wave may be written

$$V_0 + V'_1 \sin \omega t + V'_2 \sin 2\omega t + V'_3 \sin 3\omega t + V'_4 \sin 4\omega t + \ldots + V''_1 \cos \omega t + V''_2 \cos 2\omega t + V''_3 \cos 3\omega t + V''_4 \cos 4\omega t + \ldots \text{ volts} \quad (1)$$

where V_0 is a continuous potential, such as might be developed by a storage battery, ordinarily absent in an a.-c. generator wave, V'_1, V''_1, V'_2, V''_2, etc., maximum cyclic amplitudes of the various sine and cosine components. The even harmonics are ordinarily negligible in an a.-c. generator wave; so that V'_2, V''_2, V'_4, V''_4, etc., are ordinarily all zeros. If we count time from some moment

PROBLEM "X"

$R = 105$ OHMS. $X = 249$ OHMS.

$G = 0$ MHO. $Y = 0.001563$ MHO.

$Z = 270.233 \underline{/67^\circ 08' 08''}$

$Y = 0.001563 \underline{|90^\circ}$

$\theta = \sqrt{ZY} = \sqrt{0.422\,374\,5 \underline{/157^\circ 08' 08''}}$

$= 0.649\,903\,5 \underline{/78^\circ 34' 04''}$

$= 0.128\,8168 + j0.637\,009\,2$

CALCULATION FOR $\frac{\text{SINH}\,\theta}{\theta}$

$\text{SINH}\,\theta = 0.103\,8393 + j0.599\,735$

$= 0.6086583 \underline{/80^\circ 10' 38''}$ *

$\frac{\text{SINH}\,\theta}{\theta} = \frac{0.6086583 \underline{/80^\circ 10' 37''}}{0.649\,903\,5 \underline{/78^\circ 34' 04''}}$

$= 0.936\,536\,5 \underline{/1^\circ 36' 33''}$

= IMPEDANCE CORRECTING FACTOR.

CALCULATION FOR $\frac{\text{TANH}\,(\theta/2)}{\theta/2}$

$\frac{\theta}{2} = 0.324\,951\,8 \underline{/78^\circ 34' 04''}$

$= 0.064\,4084 + j0.318\,504\,6$

$\text{SINH}\,\frac{\theta}{2} = 0.061\,211\,22 + j0.313\,796\,3$

$= 0.319\,710\,7 \underline{/78^\circ 57' 43''}$

$\text{COSH}\,\frac{\theta}{2} = 0.951\,6754 + j0.020\,183\,2$

$= 0.951\,889\,4 \underline{/1^\circ 12' 54''}$

$\text{TANH}\,\frac{\theta}{2} = \frac{\text{SINH}(\theta/2)}{\text{COSH}(\theta/2)} = \frac{0.319\,710\,7 \underline{/78^\circ 57' 43''}}{0.951\,8894 \underline{/1^\circ 12' 54''}}$

$= 0.335\,869\,6 \underline{/77^\circ 44' 49''}$

$\frac{\text{TANH}\,(\theta/2)}{\theta/2} = \frac{0.335\,8696 \underline{/77^\circ 44' 49''}}{0.324\,951\,8 \underline{/78^\circ 34' 04''}}$

$= 1.033\,598 \overline{\backslash 0^\circ 49' 15''}$

= ADMITTANCE CORRECTING FACTOR.

CHECK, $\text{SINH}\,\theta = 2\,\text{SINH}\,\frac{\theta}{2}\,\text{COSH}\,\frac{\theta}{2} = 2 \times .0319\,7107 \underline{/78^\circ 57' 44''} \times 0.951\,8894 \underline{/1^\circ 12' 54''}$

$= 0.608\,6584 \underline{/80^\circ 10' 38''}$ (WHICH CHECKS WITH *).

FIG. 48.—Mathematical determination of correcting factors for equivalent π solution.

PROBLEM "X"

$Z = 105 + j249 = 270.233 \underline{/67^\circ 08' 08''}$ OHMS.

$Y = 0 + j0.001563 = 0.001563 \underline{|90^\circ}$ MHO.

$\theta = \sqrt{ZY} = 0.1288168 + j0.6370092$ HYP.

$\text{KV-A}_{RN} = 6000\,000 \overline{\backslash 25^\circ 50' 31''}$ WATTS.

$= 5\,400\,000 - j2\,615\,340.$

$E_{RN} = 60044.4$ VOLTS TO NEUTRAL.

$I_R = 99.92605 \overline{\backslash 25^\circ 50' 31''}$

SOLUTION FOR TANH θ_R

$\delta = \frac{E_{RN}}{I_R} = 600.888 \underline{/25^\circ 50' 31''}$ OHMS.

$Z_0 = \sqrt{\frac{Z}{Y}} = 415.805 \overline{\backslash 11^\circ 25' 56''}$ OHMS.

$\text{TANH}\,\theta_R = \frac{600.888 \underline{/25^\circ 50' 31''}}{415.805 \overline{\backslash 11^\circ 25' 56''}}$

$= 1.44512 \underline{/37^\circ 16' 27''}$

$= 1.14995 + j0.875209$ *

$= (\theta_1 + j\theta_2)$

SOLUTION FOR ANGLE θ_R

$$\text{TANH}^{-1}(\theta_1 \pm j\theta_2) = \frac{1}{2}\,\text{LOGH}\sqrt{\frac{(1+\theta_1)^2 + \theta_2^2}{(1-\theta_1)^2 + \theta_2^2}} + j\left[\frac{\pi - \text{TAN}^{-1}\left(\frac{\theta_1 + 1}{\pm\theta_2}\right) + \text{TAN}^{-1}\left(\frac{\theta_1 - 1}{\pm\theta_2}\right)}{\ }\right]$$

$$\theta_R = \frac{1}{2}\,\text{LOGH}\sqrt{\frac{(1+1.14995)^2 + 0.875209^2}{(1-1.14995)^2 + 0.875209^2}} + j\,\frac{\left(180^\circ - \text{TAN}^{-1}\frac{2.14995}{0.875209} + \text{TAN}^{-1}\frac{0.14995}{0.875209}\right)}{2}$$

$$= \frac{1}{2}\,\text{LOGH}\sqrt{\frac{4.62229 + 0.76599}{0.022485 + 0.76599}} + j\,\frac{(180^\circ - 67^\circ 50' 58'' + 9^\circ 43' 20'')}{2}$$

$= \frac{1}{2}(\text{LOGH}\ 2.61415) + j60^\circ 56' 11''$

$= \frac{1}{2}(0.960939) + j1.0635397$

$\theta_R = 0.4804695 + j1.0635397$

$\theta = 0.1288168 + j0.6370092$

$\theta_S = 0.6092863 + j1.7005489$

CHECK

$\text{SINH}\,\theta_R = 1.006572 \underline{/76^\circ 03' 36''}$

$\text{COSH}\,\theta_R = 0.69653 \underline{/38^\circ 47' 09''}$

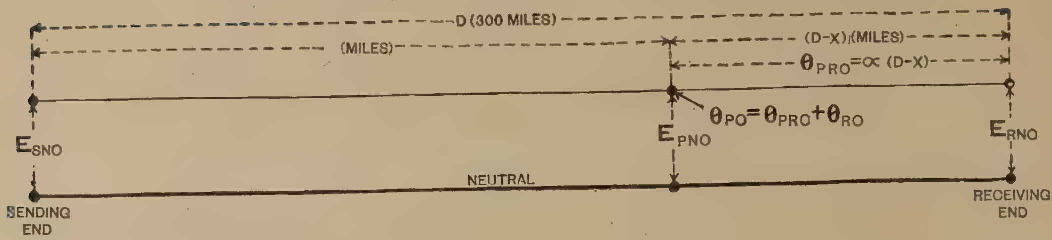
$\text{TANH}\,\theta_R = \frac{\text{SINH}\,\theta_R}{\text{COSH}\,\theta_R} = \frac{1.006572 \underline{/76^\circ 03' 36''}}{0.69653 \underline{/38^\circ 47' 09''}}$

$= 1.14995 + j0.875209$ (WHICH CHECKS WITH *).

FIG. 49.—Position angle θ_R at receiving-end.
Mathematical determination at load conditions.

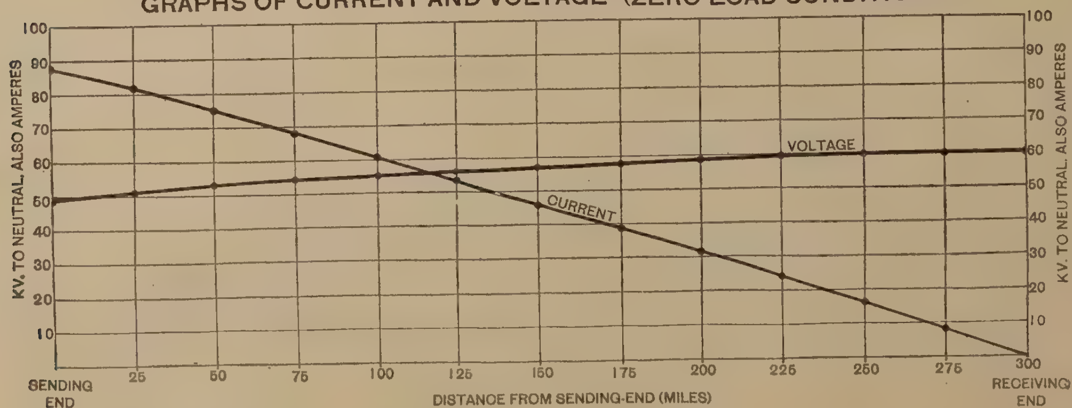
CURRENT AND VOLTAGE DISTRIBUTION

(ZERO LOAD CONDITION)



(D-X) MILES	X MILES	POSITION ANGLE $\theta_{PO}=\theta_{PRO}+\theta_{RO}$	SINH θ_{PO} (THE VOLTAGE FOLLOWS THIS COMPLEX FUNCTION)	E_{PNO} VOLTS ∠	COSH θ_{PO} (THE CURRENT FOLLOWS THIS COMPLEX FUNCTION)	I_{PO} AMPERES ∠	PF_{PO} %
0	300	0 +j1.57080 θ_2= 90°00'00"	0 +j1.00000 =1.00000 ⌊90°	60046 ∠0°	0 0 ⌊90°	0 ∠11° 25' 56"	
25	275	0.01073 +j1.62388 θ_2= 93°02'29"	0.00057+j0.99865 =0.99865 ∠89°58'03"	59965 ∠0° 01' 57"	0.05307+j0.01070 =0.05414 ∠11°23'58"	7.82 \90°01'58"	0
50	250	0.02146 +j1.67696 θ_2= 96°04'58"	0.00227+j0.99460 =0.99460 ∠89°52'09"	59803 ∠0° 07' 51"	0.10598+j0.02133 =0.10816 ∠11°22'48"	15.62 \90°03'08"	+00.12
75	225	0.03220+j1.73004 θ_2= 99°07'28"	0.00511 +j0.98785 =0.98786 ∠89°42'13"	59317 ∠0° 17' 47"	0.15866+j0.03179 =0.16181 ∠11°19'48"	23.37 \90°06'08"	+00.32
100	200	0.04294+j1.78313 θ_2= 102°09'57"	0.00905+j0.97844 =0.97847 ∠89°28'12"	58753 ∠0° 31' 48"	0.21090+j0.04199 = 0.21503 ∠11° 15'35"	31.05 \90° 10'21"	+00.61
125	175	0.05367+j1.83621 θ_2= 105°12'26"	0.01409+j0.96638 =0.96648 ∠89°09'50"	58033 ∠0° 50' 10"	0.26269+j0.051842 =0.26776 ∠11° 09' 50"	38.66 \90°16'06"	+00.99
150	150	0.06441 +j1.88930 θ_2= 108°14'56"	0.02018+j0.95168 =0.95188 ∠88°47'07"	57156 ∠1° 12' 53"	0.31380 +j0.06120 =0.31970 ∠11°02'10"	46.17 \90°23'46"	+1.42
175	125	0.07514 +j1.94238 θ_2= 111°17'25"	0.02731 +j0.93436 =0.93476 ∠88°19'33"	56129 ∠1° 40' 27"	0.36417+j0.07006 =0.37085 ∠10°53'22"	53.55 \90°32'33"	+1.98
200	100	0.08588+j1.99546 θ_2= 114°19'54"	0.03543+j0.91452 =0.91522 ∠87°46'53"	54955 ∠2° 13' 07"	0.41354+j0.07835 =0.42090 ∠10°43'41"	60.77 \90°42'15"	+2.65
225	75	0.09661 +j2.04854 θ_2= 117°22'24"	0.04449+j0.89218 =0.89328 ∠87°08'43"	53638 ∠2° 51' 17"	0.46194+j0.08593 =0.46986 ∠10°32'16"	67.85 \90°53'40"	+3.40
250	50	0.10735 +j2.10164 θ_2= 120°24'53"	0.05445+j0.86735 =0.86905 ∠86°24'28"	52183 ∠3° 35' 32"	0.50917+j0.09275 =0.51755 ∠10°19'26"	74.73 \91°06'30"	+4.33
275	25	0.11808 +j2.15473 θ_2= 123°27'22"	0.06525+j0.84014 =0.84267 ∠85°33'33"	50599 ∠4° 26' 27"	0.55514+j0.09874 =0.56385 ∠10°05'07"	81.42 \91°20'49"	+5.41
300	0	0.12882 +j2.20781 θ_2= 126°29'52"	0.07683+j0.81056 = 0.81420 ∠84°35'08"	48889 ∠5° 24' 52"	0.59973+j0.10384 =0.60865 ∠9°49'22"	87.89 \91°36'34"	+6.64

GRAPHS OF CURRENT AND VOLTAGE (ZERO LOAD CONDITIONS)



SINH $(\theta_1+j\theta_2)=(\text{SINH}\ \theta_1\ \text{COS}\ \theta_2+j\ \text{COSH}\ \theta_1\ \text{SIN}\ \theta_2)$.
COSH $(\theta_1+j\theta_2)=(\text{COSH}\ \theta_1\ \text{COS}\ \theta_2+j\ \text{SINH}\ \theta_1\ \text{SIN}\ \theta_2)$.

ANGLE AT RECEIVING END θ_{RO} = 0 +j 1.57080
ANGLE OF LINE θ =0.12882+j 0.63701
$\theta_{SO}=\theta+\theta_{RO}$ =0.12882+j 2.20781

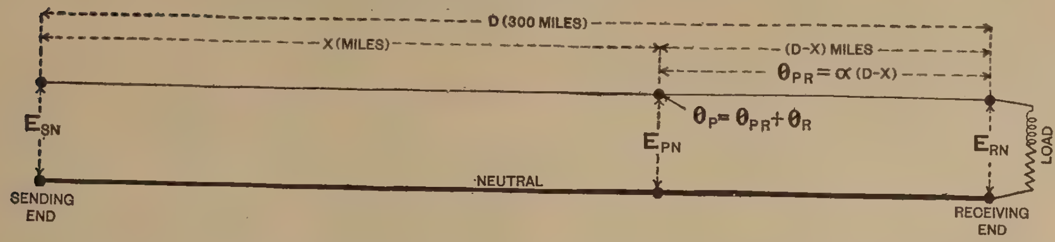
ONE QUADRANT=1.57079632 CIRCULAR RADIANS
ONE CIRCULAR RADIAN=206264.8062"=57°17' 44.8"

α =0.00042939+j 0.00212336

FIG. 50.—Current and voltage distribution.
For problem X by position angles (zero load conditions).

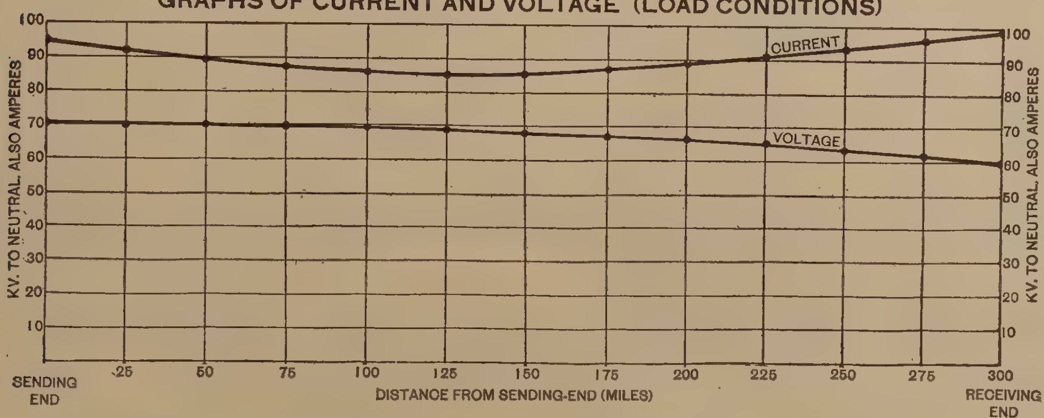
CURRENT AND VOLTAGE DISTRIBUTION

(LOAD CONDITIONS)



(D-X) MILES	X MILES	POSITION ANGLE $\theta_P = \theta_{PR} + \theta_R$	SINH θ_P (THE VOLTAGE FOLLOWS THIS COMPLEX FUNCTION)	E_{PN} VOLTS ∠	COSH θ_P (THE CURRENT FOLLOWS THIS COMPLEX FUNCTION)	I_P AMPERES ∠	PF_P %
0	300	0.48047+j1.06354 θ_2= 60°56′11″	0.24249+j0.97693 =1.00657 ∠76°03′35″	60 046 ∠0°0′0″	0.54294+j0.43632 =0.69654 ∠38°47′10″	99.92 ∖25°50′31″	−90.00
25	275	0.49120+j1.11662 θ_2= 63°58′40″	0.22426+j1.0092 =1.0338 ∠77°28′16″	61 670 ∠1°24′41″	0.49272+j0.45937 =0.67364 ∠42°59′38″	96.64 ∖21°38′03″	−93.83
50	250	0.50194+j1.16971 θ_2= 67°01′10″	0.20430+j1.0391 =1.0590 ∠78°52′36″	63 173 ∠2°49′01″	0.44064+j0.48176 =0.65288 ∠47°33′08″	93.66 ∖17°04′33″	−94.04
75	225	0.51267+j1.22279 θ_2= 70°03′39″	0.18259+j1.0663 =1.0819 ∠80°16′59″	64 540 ∠4°13′24″	0.38682+j0.50333 =0.63480 ∠52°27′25″	91.06 ∖12°10′20″	−95.94
100	200	0.52341+j1.27587 θ_2= 73°06′09″	0.15917+j1.0909 =1.1025 ∠81°41′55″	65 770 ∠5°38′20″	0.33139+j0.52399 =0.61999 ∠57°41′22″	88.94 ∖6°56′19″	−97.60
125	175	0.53414+j1.32895 θ_2= 76°08′38″	0.13409+j1.1127 =1.1207 ∠83°07′43″	66 854 ∠7°04′08″	0.27447+j0.54361 =0.60815 ∠63°12′39″	87.24 ∖1°25′02″	−98.90
150	150	0.54488+j1.38204 θ_2= 79°11′07″	0.10735+j1.1317 =1.1368 ∠84°34′52″	67 815 ∠8°31′17″	0.21618+j0.56197 =0.60211 ∠68°57′32″	86.37 ∠4°19′51″	−99.73
175	125	0.55561+j1.43512 θ_2= 82°13′36″	0.07908+j1.1477 =1.1504 ∠86°03′30″	68 626 ∠9°59′55″	0.15667+j0.57927 =0.60080 ∠74°51′57″	86.34 ∠10°14′16″	+99.99
200	100	0.56635+j1.48821 θ_2= 85°16′05″	0.04926+j1.1607 =1.1618 ∠87°34′11″	69 306 ∠11°30′36″	0.09608+j0.59508 =0.60279 ∠80°49′42″	86.47 ∠16°12′01″	+99.66
225	75	0.57708+j1.54129 θ_2= 88°18′35″	0.01798+j1.1707 =1.1708 ∠89°07′13″	69 843 ∠13°03′38″	0.03455+j0.60939 =0.60962 ∠86°45′18″	87.45 ∠22°07′39″	+98.75
250	50	0.58782+j1.59438 θ_2= 91°21′04″	−0.01471+j1.1775 =1.1775 ∠90°42′57″	70 243 ∠14°39′22″	−0.02784+j0.62207 =0.62270 ∠92°33′44″	89.33 ∠27°56′03″	+97.32
275	25	0.59855+j1.64746 θ_2= 94°23′34″	−0.04863+j1.1811 =1.1821 ∠92°21′28″	70 517 ∠16°17′53″	−0.09073+j0.63306 =0.63953 ∠98°09′22″	91.74 ∠34°11′41″	+95.17
300	0	0.60929+j1.70055 θ_2= 97°26′03″	−0.08381+j1.1814 =1.1844 ∠94°03′28″	70 652 ∠17°59′53″	−0.15416+j0.64226 =0.66050 ∠103°29′45″	94.75 ∠38°52′04″	+93.43

GRAPHS OF CURRENT AND VOLTAGE (LOAD CONDITIONS)



SINH $(\theta_1 + j\,\theta_2) = (\text{SINH}\,\theta_1\ \text{COS}\,\theta_2 + j\,\text{COSH}\,\theta_1\ \text{SIN}\,\theta_2)$.
COSH $(\theta_1 + j\,\theta_2) = (\text{COSH}\,\theta_1\ \text{COS}\,\theta_2 + j\,\text{SINH}\,\theta_1\ \text{SIN}\,\theta_2)$.

ANGLE AT RECEIVING END θ_R = 0.48047+ j1.06354
ANGLE OF LINE θ = 0.12882+ j0.63701
$\theta_S = \theta + \theta_R$ = 0.60929+ j1.7005

ONE QUADRANT=1.57079632 CIRCULAR RADIANS.
ONE CIRCULAR RADIAN=206264.8062″=57° 17′ 44.8″.

α = 0.00042939+j 0.00212336.

FIG. 51.—Current and voltage distribution.
For problem X by position angles (load conditions).

when the fundamental component passes through zero in the positive direction, $V''_1 = 0$ and the series becomes

$$V'_1 \sin \omega t + V'_3 \sin 3\omega t + V'_5 \sin 5\omega t + \ . \ . \ . \ V''_3 \cos 3\omega t + V''_5 \cos 5\omega t + \ . \ . \ . \quad \text{volts} \quad (2)$$

Compounding sine and cosine harmonic components into resultant harmonics of displaced phase, this may be expressed as

$$V_{r1}\sin\omega t + V_{r3}\sin(3\omega t + \beta_3^\circ) + V_{r5}\sin(5\omega t + \beta_5^\circ) + \ . \ . \ . \quad \text{volts} \quad (3)$$

where

$$V_{rn} = \sqrt{V'^2_n + V''^2_n} \qquad \text{volts} \quad (4)$$

and

$$\tan \beta_n^\circ = \frac{V''_n}{V'_n} \qquad \text{numeric} \quad (5)$$

Formulas (1) and (2) give the wave analysis in *sine and cosine harmonics*, while (3) gives it in *resultant sine harmonics*.

"When considering a plural-frequency alternating-current line, we require to know the harmonic analysis of the impressed potential, either in sine and cosine harmonics, or in resultant harmonics. The latter analysis is preferable, as being shorter and containing fewer terms. A decision must be made as to the number of frequencies or upper harmonics which must be taken into account.

"Ordinarily, the sizes of the harmonics diminish as their order increases; but there are numerous exceptions to this rule, as when some particular tooth frequency in the alternating-current generator establishes a prominent size for that harmonic. Care must therefore be exercised not to exclude any important harmonics. On the other hand, the fewer the harmonics to be dealt with, the better, because the labor involved in correctly solving the problem increases in nearly the same ratio as the number of harmonics retained.

"The rule is to work out the position angle, r.m.s. potential, and r.m.s. current distributions, over the artificial or conjugate smooth line, for each harmonic component in turn, as though it existed alone, and then to combine them, at each position, in the well-known way for root mean squares.

"*Combination of Components of Different Frequencies into a R.m.s. Resultant.*—Let the r.m.s. value of each alternating-current harmonic component be obtained by dividing its amplitude with $\sqrt{2}$ in the usual way, and let

$$V_n = \frac{V_{rn}}{\sqrt{2}} = \sqrt{\frac{V'^2_n + V''^2_n}{2}} \qquad \text{r.m.s. volts} \quad (6)$$

be the r.m.s. value of the nth harmonic. Then the r.m.s. value of all the harmonics together, over any considerable number of cycles, will be

$$V = \sqrt{V_1^2 + V_2^2 + V_3^2 + \ . \ . \ .} \quad \text{r.m.s. volts} \quad (7)$$

or, as is well known, the joint r.m.s. value of a plurality of r.m.s. values of different frequency, is the square root of the sum of their squares. If a continuous potential V_o be present, this may be regarded as a r.m.s. harmonic of zero frequency, and be included thus:

$$V = \sqrt{V_0^2 + V_1^2 + V_2^2 + V_3^2 + \ . \ . \ .} \quad \text{r.m.s. volts} \quad (8)$$

Moreover, from (4), it is evident that the squares of the r.m.s. values of the sine and cosine terms of any harmonic may be substituted for the square of their resultant; or that, in this respect, the sine and cosine terms may be treated as though they were components of different frequencies.

"The same procedure applies to plural-frequency currents. Find the r.m.s. resultant harmonics. The r.m.s. value of all together will be the square root of the sum of their squares. A continuous current, if present, may be included, as the r.m.s. value of an alternating current of zero frequency.

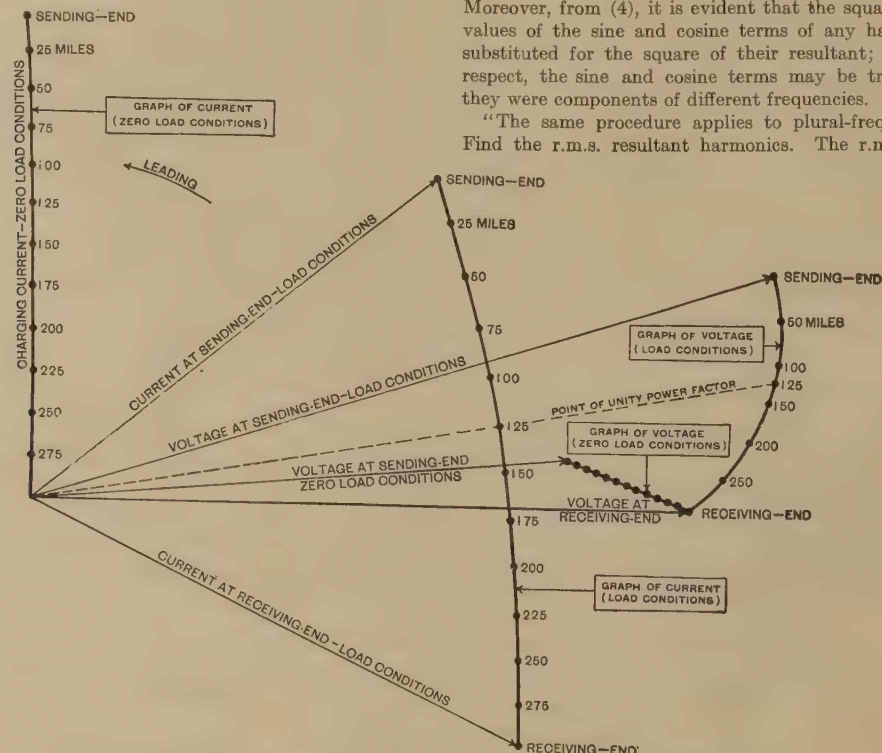


FIG. 52.—Polar diagram of current and voltage distribution for Problem X.

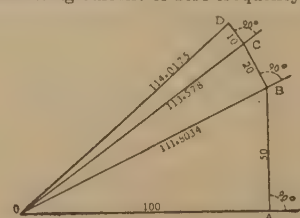


FIG. 53.—Geometrical representation of a joint r.m.s. value of plural-frequency components by perpendicular summation or "crab addition."

"*Graphical Representation of R.m.s. Plural-frequency Combination.*—The process represented algebraically in (7) or (8) may be represented graphically by the process of successive per-

pendicular summation, or "crab addition." An example will suffice to make this clear. A fundamental alternating current of 100 amp. r.m.s., is associated with a continuous current of 50 amp., and with two other alternating currents of other frequencies of 20 and 10 amp. r.m.s., respectively. What will be the joint r.m.s. current? Here by (8),

$$I = \sqrt{100^2 + 50^2 + 20^2 + 10^2} = \sqrt{10{,}000 + 2{,}500 + 400 + 100}$$
$$= \sqrt{13{,}000} = 114.0175 \text{ amp. r.m.s.}$$

"In Fig. 53, OA represents the fundamental r.m.s. current. AB, added perpendicularly to OA represents the continuous current, or current of 50 r.m.s. amp. at zero frequency. The perpendicular sum of OA and AB is OB = 111.8034 amp. Adding similarly the other frequency components BC and CD, the total perpendicular sum is OD = 114.0175 amp. The order in which the components are added manifestly does not affect the final result, and it is a matter of insignificance whether the various frequencies coacting are "harmonic," *i.e.*, are integral multiples of a fundamental, or not, so long as they are different.

"The complete solution of an alternating-current line with complex harmonic potentials and currents thus requires an independent solution of potential and current for each single frequency in turn, as though the others were non-existent, and then the r.m.s. value at any point on the line is the perpendicular sum of the separate frequency values. The powers and energies of the different frequencies are independent of each other, and the total transmitted energy is the sum of the energies transmitted at the separate component frequencies."

Bibliography

In order to give due prominence to some of the valuable contributions on the subject of performance of electrical circuits and as an acknowledgment to their authors of the assistance received from a study of them, the following publications are suggested as representing a very helpful and valuable addition to the library of the transmission engineer. They are given in the approximate order of their publication:

Calculation of the High Tension Line and Output and Regulation in Long Distance Lines by Percy H. Thomas. (Published in *A. I. of E. E. Trans.* Vol. XXVIII, Part, 1, 1909.) The former paper introduces a so-called "wave formula" for determining the performance of long lines having considerable capacity which embodies the use of algebra only. The second paper suggests the use of split conductors in order to adjust the ratio of the capacity and inductance of the line so that the leading and lagging components more nearly neutralize each other.

Formulae, Constants and Hyperbolic Constants by W. E. Miller. (Published in *G. E. Review*, supplement dated May, 1910.) This is a treatise upon the subject wherein hyperbolic functions of complex angles are tabulated for sinh and cosh $(x + jy)$ up to $x = 1$, $y = 1$ in steps of 0.02.

Transmission Line Formulas by H. B. Dwight. (Published by John Wiley & Sons, Inc.) This book introduces what are known as "Dwight's '*K*' formulas," which permit the solution of transmission problems without the use of mathematics higher than arithmetic. It also contains working formulas based upon convergent series and the solution of many problems both by the *K* formulas and by convergent series.

Tables of Complex Hyperbolic and Circular Functions by Dr. A. E. Kennelly. (Published by the Harvard University Press.) This book gives functions of complex angles for polar values up to 3.0 by steps of 0.1 and for angles from 45° to 90° by steps of one degree; also functions in terms of rectangular coordinates $x + jy$ to $x = 10$ by steps of 0.05 and of y virtually to infinity by steps of 0.05.

Chart Atlas of Complex Hyperbolic and Circular Functions by Dr. A. E. Kennelly. (Published by Harvard University Press in large charts, 48 by 48 cm.) Presenting curves for all the tables published in above referred to "Tables of Complex Hyperbolic and Circular Functions" for rapid graphical interpolation.

Constant Voltage Transmission by H. B. Dwight. (Published by John Wiley & Son, Inc.) Embraces a very complete study of the use of over-excited synchronous motors for controlling the voltage of transmission.

The Application of Hyperbolic Functions to Electrical Engineering Problems by Dr. A. E. Kennelly. (Published by the McGraw-Hill Book Co.) Every student should have a copy of this book because of its simplicity and completeness in explaining the application of hyperbolic functions to transmission circuit problems. It also contains a very complete bibliography of publications upon this general subject.

Artificial Electric Lines by Dr. A. E. Kennelly. (Published by McGraw-Hill Book Co.) This is a valuable treatise in which the subject is treated in accordance with the hyperbolic theory.

TABLE P—SUBDIVISIONS OF A DEGREE

SECONDS TO DEGREES		MINUTES TO DEGREES		DEGREES TO MINUTES AND SECONDS					
″ =	°	′ =	°	° =	′	″	° =	′	″
01	0.0003	01	0.0167	0.001	00	03.6	0.006	00	21.6
02	0.0006	02	0.0333	0.002	00	07.2	0.007	00	25.2
03	0.0008	03	0.0500	0.003	00	10.8	0.008	00	28.8
04	0.0011	04	0.0667	0.004	00	14.4	0.009	00	32.4
05	0.0014	05	0.0833	0.005	00	18.0	0.010	00	36.0
06	0.0017	06	0.1000						
07	0.0019	07	0.1167						
08	0.0022	08	0.1333						
09	0.0025	09	0.1500						
10	0.0028	10	0.1667						
11	0.0031	11	0.1833	0.01	00	36	0.51	30	36
12	0.0033	12	0.2000	0.02	01	12	0.52	31	12
13	0.0036	13	0.2167	0.03	01	48	0.53	31	48
14	0.0039	14	0.2333	0.04	02	24	0.54	32	24
15	0.0042	15	0.2500	0.05	03	00	0.55	33	00
16	0.0044	16	0.2667	0.06	03	36	0.56	33	36
17	0.0047	17	0.2833	0.07	04	12	0.57	34	12
18	0.0050	18	0.3000	0.08	04	48	0.58	34	48
19	0.0053	19	0.3167	0.09	05	24	0.59	35	24
20	0.0055	20	0.3333	0.10	06	00	0.60	36	00
21	0.0058	21	0.3500	0.11	06	36	0.61	36	36
22	0.0061	22	0.3667	0.12	07	12	0.62	37	12
23	0.0064	23	0.3833	0.13	07	48	0.63	37	48
24	0.0067	24	0.4000	0.14	08	24	0.64	38	24
25	0.0069	25	0.4167	0.15	09	00	0.65	39	00
26	0.0072	26	0.4333	0.16	09	36	0.66	39	36
27	0.0075	27	0.4500	0.17	10	12	0.67	40	12
28	0.0078	28	0.4667	0.18	10	48	0.68	40	48
29	0.0081	29	0.4833	0.19	11	24	0.69	41	24
30	0.0083	30	0.5000	0.20	12	00	0.70	42	00
31	0.0086	31	0.5167	0.21	12	36	0.71	42	36
32	0.0089	32	0.5333	0.22	13	12	0.72	43	12
33	0.0092	33	0.5500	0.23	13	48	0.73	43	48
34	0.0094	34	0.5667	0.24	14	24	0.74	44	24
35	0.0097	35	0.5833	0.25	15	00	0.75	45	00
36	0.0100	36	0.6000	0.26	15	36	0.76	45	36
37	0.0103	37	0.6167	0.27	16	12	0.77	46	12
38	0.0106	38	0.6333	0.28	16	48	0.78	46	48
39	0.0108	39	0.6500	0.29	17	24	0.79	47	24
40	0.0111	40	0.6667	0.30	18	00	0.80	48	00
41	0.0114	41	0.6833	0.31	18	36	0.81	48	36
42	0.0117	42	0.7000	0.32	19	12	0.82	49	12
43	0.0119	43	0.7167	0.33	19	48	0.83	49	48
44	0.0122	44	0.7333	0.34	20	24	0.84	50	24
45	0.0125	45	0.7500	0.35	21	00	0.85	51	00
46	0.0128	46	0.7667	0.36	21	36	0.86	51	36
47	0.0130	47	0.7833	0.37	22	12	0.87	52	12
48	0.0133	48	0.8000	0.38	22	48	0.88	52	48
49	0.0136	49	0.8167	0.39	23	24	0.89	53	24
50	0.0139	50	0.8333	0.40	24	00	0.90	54	00
51	0.0141	51	0.8500	0.41	24	36	0.91	54	36
52	0.0144	52	0.8667	0.42	25	12	0.92	55	12
53	0.0147	53	0.8833	0.43	25	48	0.93	55	48
54	0.0150	54	0.9000	0.44	26	24	0.94	56	24
55	0.0153	55	0.9167	0.45	27	00	0.95	57	00
56	0.0156	56	0.9333	0.46	27	36	0.96	57	36
57	0.0159	57	0.9500	0.47	28	12	0.97	58	12
58	0.0162	58	0.9667	0.48	28	48	0.98	58	48
59	0.0164	59	0.9833	0.49	29	24	0.99	59	24
60	0.0167	60	1.0000	0.50	30	00	1.00	60	00

EXAMPLES

$0^\circ.41 = 0^\circ\ 24'\ 36''$ $\qquad$ $0^\circ\ 41'\ 00'' = 0^\circ.6833.$

$0^\circ.005 = 0^\circ\ 00'\ 18''$ $\qquad$ $0^\circ\ 00'\ 46'' = 0^\circ.0128.$

Electrical Phenomena in Parallel Conductors by Dr. F. E. Pernot. (Published by John Wiley & Son, Inc.) Being a very recent treatise, this book contains much practical and many readily understandable explanations for both the beginner and those further advanced in the study of this subject. It contains a six-place table of logarithms of real hyperbolic functions for values of x from 0.000 to 2.000 for intervals of 0.001 in the argument. This is the most complete table of real hyperbolic functions which the author has seen.

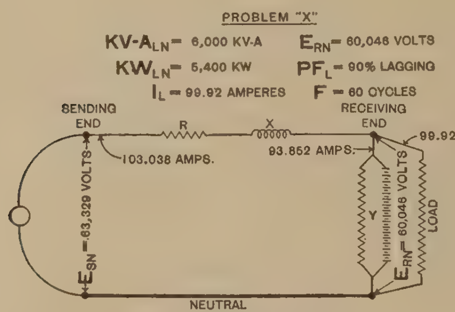
CHAPTER XI

COMPARISON OF VARIOUS METHODS FOR CALCULATING PERFORMANCE

The "localized capacitance" or "localized admittance" methods are discussed below for the two following reasons. A discussion of them is of academic interest and a tabulation of the magnitude of the errors in the results as obtained by these approximate methods when applied to circuits of different lengths and frequencies should be helpful. These methods may be carried out either graphically or mathematically, but since they are only approximate the simpler graphical solution should suffice. Their principal virtue is the fact that they simplify the determination of performance, but this is obtained at the expense of accuracy. The more accurate of these methods is somewhat tedious to carry out. The graphical solution previously described in connection with the Wilkinson Charts will be generally more accurate and shorter than these localized capacitance methods.

The localized capacitance methods are: the single-end condenser method; the middle condenser or T method; the split condenser or nominal π method and Dr. Steinmetz's three condenser method. These four lumped capacitance methods assume the total capacitance of the circuit as being divided up and "lumped" in the form of condensers shunted across the circuit at one or more points. By averaging the values, as obtained by the impedance and single-end condenser methods, usually an approximation to the true value may be obtained.

The middle condenser or T method assumes that the total capacitance may be shunted across the circuit at the middle point. On this assumption the total charging current will flow over one-half the length of the circuit. This method is therefore more nearly accurate than the single condenser method.



RESULTS CALCULATED BY

RIGOROUS SOLUTION	SINGLE END CONDENSER METHOD	% ERROR
E_{SN} = 70,652 VOLTS	63,329 VOLTS	− 10.37%
I_S = 94.75 AMPS.	103.038 AMPS	+ 8.8%
PF_S = + 93.42%	+ 99.927%	+ 7.0%
$LOSS_N$ = 855 KW	1120 KW	+ 30.9%

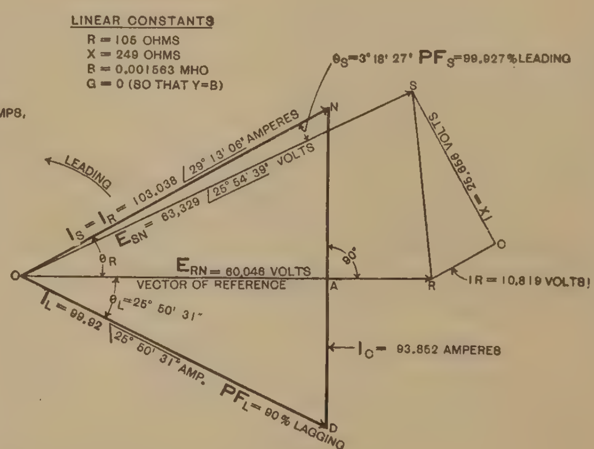


FIG. 54.—Single end condenser method. Problem X.

The single condenser method assumes the total capacitance as being lumped or shunted across the circuit at the receiving end. On this assumption the total charging current for the circuit would flow over the entire circuit. Actually the charging current is distributed along the circuit so that the entire charging current does not flow over the entire circuit. Obviously the assumption of the total capacitance being lumped at the receiving end will therefore give over compensation for the effect of the charging current upon the voltage regulation of the circuit. This method of solution yields a voltage too low at the sending end by nearly the same amount that the straight impedance method gives it too high. By averaging the values, as obtained by the impedance and single-end condenser

The split condenser or π method assumes one-half the capacitance being shunted across the circuit at each end. In this case one-half of the charging current flows over the entire circuit. This assumed distribution of the charging current also more nearly represents the actual distribution than the single condenser method.

Dr. Steinmetz has proposed a method assuming three condensers shunted across the circuit, one in the middle, of two-thirds, and one at each end, each of one-sixth the total capacitance of the circuit. This method is equivalent to assuming that the electrical quantities are distributed along the circuit in a way representing an arc of a parabola. This method assumes one-sixth the charging current flowing over one-half the entire circuit and five-sixth the charging

current flowing over the other half of the circuit. This method gives quite accurate results unless the circuit is very long and the frequency high.

Figures 54–57 show leaky condensers placed at different points of the circuits, that is they indicate that there is a leak G, as well as a susceptance B. For simplicity pure condensers have been assumed in the accompanying calculations; that is we have assumed $G = o$. This is the usual assumption in such cases, for the reason that G is usually very small, and localized capacitance methods are approximations at best. In the equivalent π solution previously given, we have indicated the treatment when the condensers have a leak. In this case, however, the equivalent π method produces exact results, and the nature of such solution may demand a condenser having a material leak.

AUXILIARY CONSTANTS

Mr. T. A. Wilkinson and Dr. Kennelly have worked out the algebraic expressions for the auxiliary constants corresponding to these four circuits of localized capacitance. These are given in Table Q. It may be interesting to observe to what extent each of the four localized capacitance methods takes account of the three linear line constants R, X and B. The rigorous or exact expression for the auxiliary constants is given under Table Q for comparison with the values corresponding to the localized condenser methods. The numerals under the algebraic expressions correspond to problem X; that is, to a certain 60-cycle circuit, 300 miles long. They are given to illustrate for a long circuit, the account taken of the fundamental constants for each of the five methods listed. These numerals may be compared with the rigorous or exact values as given under the rigorous expressions at the bottom of the table.

It should be noted that in all the cases in table Q except the single end condenser case the auxilary constants shown are correct for both voltage and current calculations. In the single end condenser case, which alone of the five cases forms an unsymmetrical circuit, the components of the B and C constants are also correct for both voltage and current but the components a_1 and a_2 as tabulated apply only to voltage calculations. For current calculations the value of a_1 is 1 and that of a_2 is 0.

SINGLE END CONDENSER METHOD

This method assumes that the total capacitance of the circuit may be concentrated across the circuit at the receiving end. In such case the entire charging current would flow over the total length of the circuit.

Solution by Impedance Method.—The diagrams of connections and corresponding graphical vector solution for problem X by the single-end condenser method are indicated by Fig. 54. The current DN consumed by the condenser (zero leakage assumed) leads the receiving-end voltage OR by 90 degrees and is,

$$I_c = 0.001563 \times 60.046 = 93.852 \text{ amp.}$$

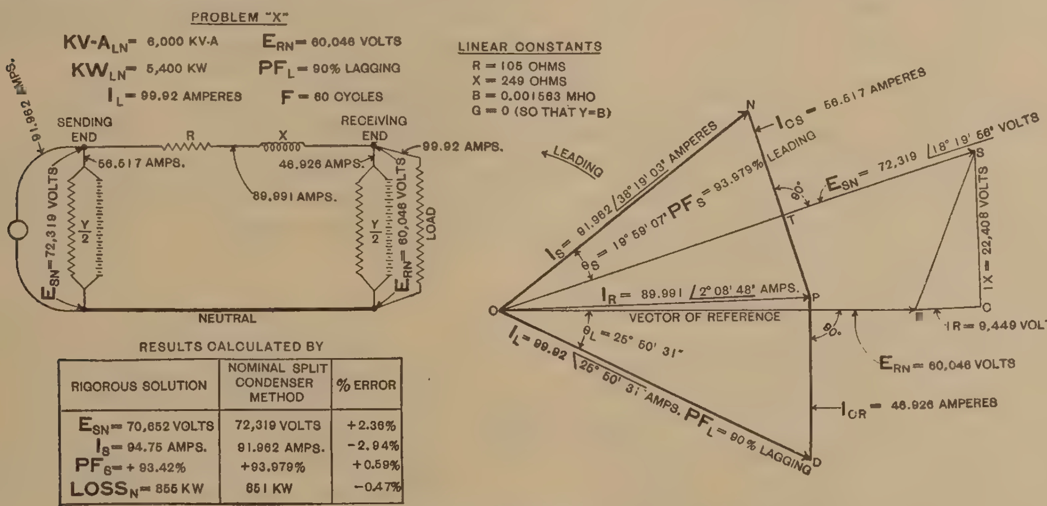


FIG. 55.—Nominal π or split condenser method.
Problem X.

The load current of 99.92 amp., lagging 25° 50′ 30″ (90 per cent power-factor) has a component OA of $99.92 \times 0.90 = 89.928$ amp. in phase with the receiving-end voltage and a component AD of $99.92 \times 0.4359 = 43.555$ amp. in lagging quadrature with the receiving-end voltage. This lagging component is therefore in opposite direction to the charging current, the effect of which is to neutralize an equivalent amount of charging current. The remaining current AN in leading quadrature with the receiving-end voltage is $93.852 - 43.555 = 50.297$ amp. The current ON in the conductor is therefore:

$$I_r = \sqrt{(89.928)^2 + (50.297)^2}$$
$$= 103.038 \text{ amp.}$$

The current at the sending-end leads the voltage at the receiving end by the angle θ_R whose tangent is,

$$\frac{50.297}{89.928} = \tan 29° \, 13' \, 06''$$

The voltage consumed by the resistance and the reactance of each conductor is,

$$IR = 103.038 \times 105 = 10{,}819 \text{ volts (resistance drop)}$$
$$IX = 103.038 \times 249 = 25{,}656 \text{ volts (reactance drop)}$$

The receiving-end conditions are thus,

$$I_r = 103.038 \text{ amp.}$$
$$\theta_r = 29° \, 13' \, 06''$$
$$\cos \theta_r = 0.8772$$
$$\sin \theta_r = 0.4881$$

and from (40)

$$E_{sn} = \sqrt{(60{,}046 \times 0.8727 + 10{,}819)^2 + (60{,}046 \times 0.4881 - 25{,}656)^2}$$
$$= 63{,}329 \diagdown 3° \, 18' \, 27'' \text{ volts to vector } ON$$
$$= 63{,}329 \, \underline{/25° \, 54' \, 39''} \text{ volts to vector of reference}$$

$$P.F._s = \cos \underline{/3° \, 18' \, 27''} = 99.927 \text{ per cent leading}$$
$$Kv.a._{sn} = 103.038 \times 63.329 = 6{,}525 \text{ kv.a.}$$
$$Kw_{sn} = 6{,}525 \times 0.99927 = 6{,}520 \text{ kw.}$$
$$Loss_n = 6{,}520 - 5{,}4000 = 1{,}120 \text{ kw.}$$

which checks exactly with the results as obtained previously by the impedance method.

The current at the sending end may be determined as follows:

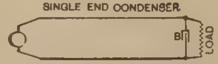
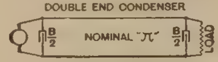
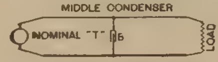
$$I_l \, (\cos \theta_l - j \sin \theta_l) = 89.928 - j43.555$$
$$+E_{sn} \, (c_1 + j \, c_2) = 0 + j93.852$$
$$I_s = 89.928 + j50.297$$
$$= 103.038 \, \underline{/29° \, 13' \, 06''} \text{ amp.}$$

which also checks exactly with the result as previously determined by the impedance method.

It should be noted here that in determining the sending-end current, the auxiliary constant $(a_1 + ja_2)$ did not enter into the calculation as it does in the rigorous solution; this is owing to the inherent dissymmetry of the single-end condenser. This is the only case in which the capacitance is applied dissymmetrically, consequently the current entering the line at the sending-end is completely determined by the load current at the receiving end and the vector addition thereto of the current supplied at that end to the condenser under receiving-end voltage. For determining the sending-end voltage $A'_v = 1 + YZ$ and $B'_v = Z$; but for determining the sending-end current $A'_I = 1$ and $C'_I = Y$. If the condenser were applied symmetrically A'_v *and* A'_I would be identical.

TABLE Q—AUXILIARY CONSTANTS

CORRESPONDING TO CIRCUITS OF LOCALIZED CAPACITANCE

METHOD	a_1	a_2	b_1	b_2	c_1	c_2	EQUIVALENT CONVERGENT SERIES FORM OF EXPRESSION ★
IMPEDANCE	1	0	R $= 105$	X $= +j\,249$	0	0	$A' = 1$ $B' = Z$ $C' = 0$
SINGLE END CONDENSER 	$1 - XB$ $= 0.610813$	RB $= +j\,0.164115$	R $= 105$	X $= +j\,249$	0	B $= +j\,0.001563$	$A' = 1 + YZ$ $B' = Z$ $C' = Y$
DOUBLE END CONDENSER 	$1 - \frac{XB}{2}$ $= 0.8054065$	$\frac{RB}{2}$ $= +j\,0.082058$	R $= 105$	X $= +j\,249$	$-\frac{B^2R}{4}$ $= -0.000\,0641$	$B - \frac{B^2X}{4}$ $= +j\,0.001411$	$A' = \left(1 + \frac{YZ}{2}\right)$ $B' = Z$ $C' = Y\left(1 + \frac{YZ}{4}\right)$
MIDDLE CONDENSER 	$1 - \frac{XB}{2}$ $= 0.8054065$	$\frac{RB}{2}$ $= +j\,0.082058$	$R - \frac{RXB}{2}$ $= 84.5677$	$X - \frac{B}{4}(X^2 - R^2)$ $= +j\,229.081$	0	B $= +j\,0.00156$	$A' = \left(1 + \frac{YZ}{2}\right)$ $B' = Z\left(1 + \frac{YZ}{4}\right)$ $C' = Y$
THREE CONDENSER 	$1 - \frac{XB}{2} + \frac{B^2}{36}(X^2 - R^2)$ $= 0.808866$	$\frac{RB}{2} - \frac{RXB^2}{18}$ $= +j\,0.0785091$	$R - \frac{RXB}{3}$ $= 91.3785$	$X - \frac{B}{6}(X^2 - R^2)$ $= +j\,236.721$	$-\frac{5RB^2}{36} + \frac{RXB^3}{105}$ $= -0.000\,0347$	$B - \frac{5XB^2}{36} + \frac{B^3}{216}(X^2 - R^2)$ $+j\,0.0014794$	$A' = \left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{36}\right)$ $B' = Z\left(1 + \frac{YZ}{6}\right)$ $C' = Y\left(1 + \frac{5YZ}{36} + \frac{Y^2Z^2}{216}\right)$

★ THE EXACT OR RIGOROUS EXPRESSIONS FOR THE AUXILIARY CONSTANTS ARE GIVEN BELOW   THE NUMERICAL FIGURES CORRESPOND TO PROBLEM "X"

$$A = \left(1 + \frac{YZ}{2} + \frac{Y^2Z^2}{24} + \frac{Y^3Z^3}{720} + \frac{Y^4Z^4}{40\,320} + \right) = \cosh \theta = 0.81056 + j0\,07683$$

$$B = Z\left(1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \right) = Z_0 \sinh \theta = 91\,7486 + j235.866$$

$$C = Y\left(1 + \frac{YZ}{6} + \frac{Y^2Z^2}{120} + \frac{Y^3Z^3}{5{,}040} + \frac{Y^4Z^4}{362{,}880} + \right) = Y_0 \sinh \theta = -0.000\,0411 + j\,0.0014634$$

Solution by Complex Quantities.—From Table Q the auxiliary constants corresponding to the single-end condenser method are found as follows:

$$a_1 = 1 - XB = 0.610813$$
$$a_2 = RB = 0.164115$$
$$b_1 = R = 105 \text{ ohms.}$$
$$b_2 = X = 249 \text{ ohms.}$$
$$c_1 = O$$
$$c_2 = B = 0.001563 \text{ mho.}$$

The voltage at the sending end is determined as follows:

$$I_l \, (\cos \theta_l - j \sin \theta_l) = 89.928 - j\,43.555$$
$$\times (b_1 + jb_2) = 20{,}286 + j\,17{,}819$$
$$+ E_{sn} \, (a_1 + ja_2) = 36{,}677 + j\,\;9{,}854$$
$$E_{sn} = 56{,}963 + j\,27{,}673$$
$$= 63{,}329 \, \underline{/25° \, 54' \, 39''} \text{ volts}$$

SPLIT CONDENSER OR NOMINAL π SOLUTION

This method assumes that the total capacitance of the circuit may be concentrated at the two ends, one-half being placed across the circuit at either end. In this case one-half the charging current flows over the entire circuit. The total resistance and the total reactance of one conductor is placed between the two terminal condensers.

With this assumption the current consumed by the condenser across the receiving end of the circuit is added vectorially to the load current and the power-factor of the combined currents calculated. With these new load conditions determined the conditions at the

sending end are calculated by the impedance method. This is the only calculation required when employing the nominal π method for determining the sending-end voltage. The voltage at the sending end is therefore more readily calculated by this method than by the T method which requires the calculation of the two separate halves of the circuit. If, however, the current, power-factor and kw. input are required, a second calculation must be made to determine them. In such cases the current consumed by the condenser at the sending end must be added vectorially to that of the line conductors.

Solution by Impedance Method.—The diagrams of connections and corresponding graphical vector solutions for problem X by the nominal π method are indicated in Fig. 55. The charging current consumed by the condenser (zero leakage assumed) at the receiving end of the circuit leads the receiving-end voltage by 90 degrees and is,

$$I_{cr} = \frac{0.001563}{2} \times 60{,}046 = 46.926 \text{ amp.}$$

The current I_r in each conductor is the vector sum of the load and condenser currents and may be determined as follows:

$$I_r = \sqrt{(99.92 \times 0.90)^2 + (I_{cr} + 99.92 \times -0.4359)^2}$$
$$= 89.991 \,/\underline{2^\circ\ 08'\ 48''} \text{ amp.}$$

$$P.F._{r} = \cos 2^\circ\ 08'\ 48'' = 99.33 \text{ per cent leading}$$

The voltage consumed by the resistance and the reactance of each conductor is,

$$IR = 89.991 \times 105 = 9{,}449 \text{ volts (resistance drop)}$$
$$IX = 89.991 \times 249 = 22{,}408 \text{ volts (reactance drop)}$$

and from (40),

$$E_{sn} =$$
$$\sqrt{(60{,}046 \times 0.9933 + 9{,}449)^2 + (60{,}046 \times 0.037458 - 22{,}408)^2}$$
$$= 72{,}319 \,/\underline{16^\circ\ 11'\ 08''} \text{ volts to current vector } OP$$
$$= 72{,}319 \,/\underline{18^\circ\ 19'\ 56''} \text{ volts to vector of reference } OR$$

The charging current consumed by the condenser at the sending-end (zero leakage assumed) leads the voltage at the sending-end by 90° and is,

$$I_{cs} = \frac{0.001563}{2} \times 72{,}319 = 56.517 \text{ amp.}$$

The current at the sending end is the vector sum of the current in the conductor and the current consumed by the condenser at the sending end. It may be calculted as follows:

$$OT = 89.991 = 86.424 \text{ amp.}$$
$$TP = 89.991 = 25.085 \text{ amp.}$$
$$TN = 56.517 - 25.085 = 31.432 \text{ amp.}$$

therefore,

$$I_s = \sqrt{86.424^2 + 31.432^2}$$
$$= 91.962 \,/\underline{19^\circ\ 59'\ 07''} \text{ amp. to vector } OS$$
$$= 91.962 \,/\underline{38^\circ\ 19'\ 03''} \text{ to vector of reference } OR$$

$$P.F._{s} = \cos 19^\circ\ 59'\ 07'' = 93.979 \text{ per cent leading}$$
$$Kv.a._{sn} = 91.962 \times 72.319 = 6{,}651 \text{ kv.a.}$$
$$Kw._{sn} = 6{,}651 \times 0.93979 = 6{,}251 \text{ kw.}$$
$$Loss_n = 6{,}251 - 5{,}400 = 851 \text{ kw.}$$
$$\text{Eff.} = \frac{5{,}400 \times 100}{6{,}251} = 86.37 \text{ per cent.}$$

Solution by Complex Quantities.—Fron Table Q the auxiliary constants corresponding to the nominal π method of solution are found as follows:

$$a_1 = 1 - \frac{XB}{2} = 0.8054065.$$
$$a_2 = \frac{RB}{2} = 0.0820575.$$
$$b_1 = R = 105 \text{ ohms}$$
$$b_2 = X = 249 \text{ ohms}$$
$$c_1 = -\frac{B^2R}{4} = -0.0000641 \text{ mho}$$
$$c_2 = B - \frac{B^2X}{4} = 0.001411 \text{ mho}$$

The voltage at the sending end is determined as follows:

$$\begin{aligned} I_l (\cos\theta_l - j\sin\theta_l) &= 89.928 - j43.555. \\ \times(b_1 + jb_2) &= 20{,}286 + j17{,}819 \text{ volts} \\ +E_{rn}(a_1 + ja_2) &= \underline{48{,}361 + j\ 4{,}927} \text{ volts} \\ E_{sn} &= 68{,}647 + j22{,}746 \\ &= 72{,}319 \,/\underline{18^\circ\ 19'\ 56''} \text{ volts} \end{aligned}$$

The current at the sending end may be determined as follows:

$$\begin{aligned} I_l (\cos\theta_l - j\sin\theta_l) &= 89.928 - j43.555 \\ \times(a_1 + ja_2) &= +76.003 - j27.700 \text{ amp.} \\ +E_{rn}(c_1 + jc_2) &= \underline{-\ 3.849 + j84.718} \text{ amp.} \\ I_s &= 72.154 + j57.018. \\ &= 91.962 \,/\underline{38^\circ\ 19'\ 03''} \text{ amp.} \end{aligned}$$

The above results check exactly with those previously obtained by impedance calculations. This agreement indicates that the nominal π solution may, if desired, be used with complex quantities, assuming values for the auxiliary constants as indicated in Table Q.

Convergent Series Expression.—Table Q indicates that the nominal π solution is equivalent to using the following values for the auxiliary constants in the convergent series form of solution,

$$A' = \left(1 + \frac{YZ}{2}\right),\ B' = Z,\ C' = Y\left(1 + \frac{YZ}{4}\right)$$

We will now show that the above expressions yield the same values for the auxiliary constants as given in Table Q. From Chart XI the following values corresponding to problem X are taken.

$$ZY = -0.389187 + j0.164115$$

therefore,

$$\begin{aligned} A' &= 1.000000 \\ &= \underline{-0.1945935 + j0.0820575} \\ A' &= 0.8054065 + j0.0820575 \\ B' &= 105 + j249 \\ C' &= \quad 1.000000 \\ &\quad \underline{-0.0972967 + j0.0410287} \\ &= Y\ (0.9027033 + j0.0410287) \\ C' &= -0.0000641 + j0.001411 \end{aligned}$$

Thus the values for the auxiliary constants as determined by the above incomplete convergent series expression check with those as determined above from the equations in Table Q.

MIDDLE CONDENSER OR NOMINAL T METHOD

This method assumes that the total capacitance of the circuit may be concentrated at its middle point. In such a case the entire charging current would flow over half of the circuit. The resistance and the reactance on each side of the capacitance or condenser is equal respectively to half the total conductor resistance and conductor reactance.

From an inspection of the diagram of such a circuit, Fig. 56, it is evident that two calculations will be required. Starting with the known receiving-end conditions, the conditions at the middle of the circuit are first calculated by the simple impedance method. To these calculated results the current consumed by the condenser shunted across the middle of the circuit must be vectorially added. This will give the load condition at the middle of the circuit from which the sending-end conditions may be calculated.

Solution by Impedance Method.—The diagram of connections and the corresponding graphical vector solution for problem X by the nominal T method are indicated by Fig. 56. The electrical conditions at the middle of the circuit may be determined as follows:

$I_r\frac{R}{2} = 99.92 \times 52.5 = 5{,}246$ volts (resistance drop)

$I_r\frac{X}{2} = 99.92 \times 124.5 = 12{,}440$ volts (reactance drop)

$E_{mn} =$
$\sqrt{(60{,}046 \times 0.9 + 5{,}246)^2 + (60{,}046 \times 0.4359 + 12{,}440)^2}$
$= 70{,}753 \ \underline{/33° \ 04' \ 36''}$ to current vector OD
$= 70{,}753 \ \underline{/7° \ 14' \ 05''}$ to vector of reference OR

The current consumed by the condenser (zero leakage assumed) leads the voltage OM at the middle of the circuit by 90 degrees and is:

$I_c = 0.001563 \times 70{,}753 = 110.587$ amp.

The voltage consumed by the condenser current flowing back to the sending-end is:

$I_c\frac{R}{2} = 110.587 \times 52.5 = 5{,}806$ volts (resistance drop)
$= FC$

$I_c\frac{X}{2} = 110.587 \times 124.5 = 13{,}768$ volts (reactance drop)
$= FM$

The voltage vector OC upon which the impedance triangle corresponding to the receiving-end load current $I_r = I_l$ flowing over the sending-end half of the circuit is constructed, may be found as follows:

$OC = \sqrt{(70{,}753 - 13{,}768)^2 + 5{,}806^2}$
$= 57{,}280 \ /5° \ 49' \ 03''$ volts to vector OM
$= 57{,}280 \ /13° \ 03' \ 8''$ volts to vector of reference OR

The voltage OC leads the receiving-end current OD by the angle $33° \ 04' \ 36'' + 5° \ 49' \ 03'' = 38° \ 53' \ 39''$ which angle corresponds to a power-factor of 77.831 per cent. The voltage at the sending end will therefore be:

$E_{sn} = \sqrt{(57{,}280 \times 0.77831 + 5{,}246)^2 + (57{,}280 \times 0.62788 + 12{,}440)^2}$
$= 69{,}467 \ \underline{/44° \ 10' \ 14''}$ volts to vector OD
$= 69{,}467 \ \underline{/18° \ 19' \ 43''}$ volts to vector of reference OR

If desired, the receiving-end current and the condenser current may be combined and the corresponding impedance triangle for the sending-end half of the circuit constructed on the end of vector OM as indicated by the dotted lines.

The current at the sending-end may be determined as follows:

$OB = 99.92 \cos 33° \ 04' \ 36'' = 83.727$ amp.
$BD = 99.92 \sin 33° \ 04' \ 36'' = 54.532$ amp.
$BN = 110.587 - 54.532 = 56.055$ amp.
$I_s = ON = \sqrt{(83.727)^2 + (56.055)^2}$
$= 100.76 \ \underline{/33° \ 48' \ 06''}$ amp. to vector OB
$= 100.76 \ \underline{/41° \ 02' \ 11''}$ amp. to vector of reference OR

The current at the sending end leads the voltage at the sending end by the angle $41° \ 02' \ 11''$—$18° \ 19' \ 43'' = 22° \ 42' \ 28''$, which corresponds to a power-factor at the sending end of 92.25 per cent leading.

The power at the sending end is

$Kv.a._{sn.} = 100.76 \times 69{,}467 = 7{,}000$ kv.a.
$Kw_{sn.} = 7{,}000 \times 0.9225 = 6{,}457$ kw.
$Loss_n = 6{,}457 - 5{,}400 = 1{,}057$ kw.

Solution by Complex Quantities.—From Table Q the auxiliary constants corresponding to the nominal T method of solution are found as follows:

$$a_1 = 1 - \frac{XB}{2} = 0.8054065$$
$$a_2 = \frac{RB}{2} = 0.0820575$$
$$b_1 = R - \frac{RXB}{2} = 84.5677$$
$$b_2 = X - \frac{B}{4}(X^2 - R^2) = 229.081$$
$$c_1 = O$$
$$c_2 = B = 0.001563$$

The voltage at the sending end is obtained as follows:

$$\begin{aligned} I_r \ (\cos \theta_r - j \sin \theta_r) &= 89.928 - j43.554. \\ \times \ (b_1 + jb_2) &= 17{,}582 + j16{,}918 \\ + \ E_{rn} \ (a_1 + ja_2) &= 48{,}361 + \ j4{,}927 \\ E_{sn} &= 65{,}943 + j21{,}845 \\ &= 69{,}467\underline{/18° \ 19' \ 43''} \end{aligned}$$

The current at the sending end may be calculated as follows:

$$\begin{aligned} I_r \ (\cos \theta_r = j \sin \theta_r) &= 89.928 - j43.554 \\ \times \ (a_1 + ja_2) &= 76.0026 - j27.6994 \\ + \ E_{rn}(c_1 + jc_2) &= \quad 0 \qquad + j93.8519 \\ I_s &= 76.0026 + j66.1525 \\ &= 100.76\underline{/41° \ 02' \ 11''} \text{ amp.} \end{aligned}$$

The above results check with those previously obtained by impedance calculations. This agreement indicates that the nominal T solution may, if desired, be made by complex quantities, assuming values for the auxiliary constants as indicated in Table Q.

Convergent Series Expression.—Table Q indicates that the nominal T solution is equivalent to using the

following values for the auxiliary constants in the convergent series form of solution:

$$A' = \left(1 + \frac{ZY}{2}\right)$$

$$B' = Z\left(1 + \frac{ZY}{4}\right)$$

$$C' = Y$$

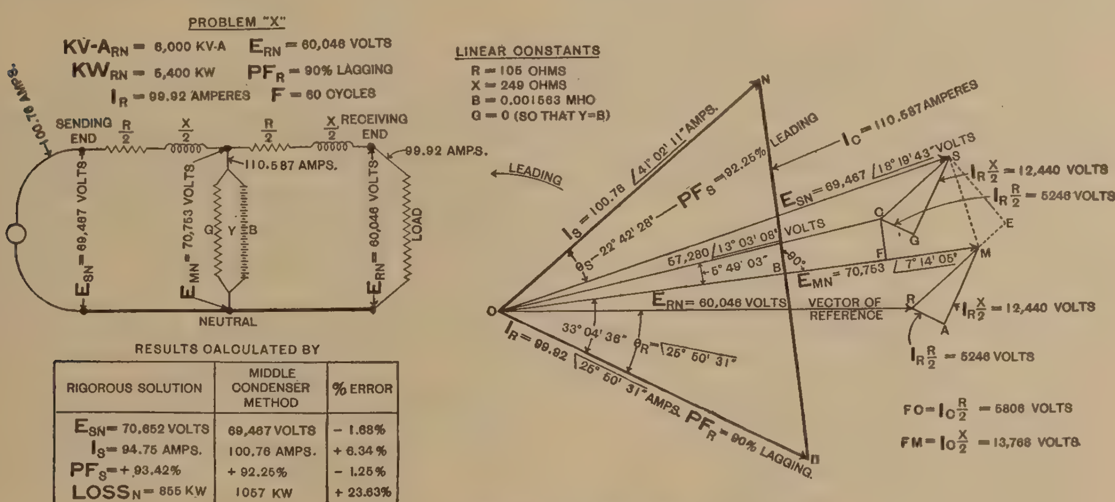
Comparing the above expressions for the auxiliary constants with the complete expression yielding rigorous values the following difference may be noted.

For auxiliary constant A' the first two terms in the complete series for the hyperbolic cosine are used and all terms beyond omitted. For auxiliary constant B' the first two terms of the complete series are also used except that the coefficient of the second term is given as ¼, whereas in the complete series it is ⅙. Auxiliary constant C' is equivalent to the first term only of the complete expression.

THREE CONDENSER METHOD

This method (proposed by Dr. Chas. P. Steinmetz) assumes that the admittance of the circuit may be lumped or concentrated across the circuit at three points, one-sixth being localized at each end and two-thirds at the middle of the circuit. This is equivalent to assuming that the electrical quantities are distributed along the circuit in a manner represented by the arc of a parabola. It is evident that this method more nearly approaches the actual distribution of the impedance and the admittance of the circuit than any of the three previously described localized admittance methods, and therefore yields more accurate results.

From an inspection of the diagram of such a circuit, Fig. 57, it will be evident that it is necessary to calculate the performance of the two halves of the circuit in order to arrive at the sending-end voltage and an additional calculation will be required to determine the sending-end current, power and power-factor.



RIGOROUS SOLUTION	MIDDLE CONDENSER METHOD	% ERROR
E_{SN} = 70,652 VOLTS	69,467 VOLTS	− 1.68%
I_S = 94.75 AMPS.	100.76 AMPS.	+ 6.34%
PF_S = + 93.42%	+ 92.25%	− 1.25%
$LOSS_N$ = 855 KW	1057 KW	+ 23.63%

FIG. 56.—Nominal T or middle condenser method.

We will now show that the above expressions yield the same values for the auxiliary constants as given in Table Q. From Chart XI the following values corresponding to problem X are taken:

$$Z = 105 + j249$$
$$ZY = -\,0.389187 + j0.164115$$

$$\text{Therefore } A' = 1.000000$$
$$-\,0.1945935 + j0.0820575$$
$$A' = +\,0.8054065 + j0.0820575$$
$$B' = 1.000000$$
$$-\,0.09729675 + j9.04102875$$
$$= Z\,(0.90270325 + j0.04102875)$$
$$B' = 84.5677 + j229.081$$
$$C' = 0 + j0.001563$$

Thus the values for the auxiliary constants as determined by the above incomplete convergent series expressions check exactly with those as determined above from the equations in Table Q.

Solution by Impedance Method.—The diagram of connections and corresponding graphical vector solution for problem X by the three condenser method is indicated by Fig. 57. The charging current consumed by the condenser (zero leakage assumed) at the receiving end leads the receiving-end voltage by 90 degrees and is

$$I_{cr} = \frac{0.001563}{6} \times 60{,}046 = 15.642 \text{ amp.}$$

The current per conductor for the receiving-end half of the circuit is:

$$I_r = \sqrt{(99.92 \times 0.9)^2 + (99.92 \times 0.4359 - 15.642)^2}$$
$$= 94.16 \diagdown 17°\ 14'\ 38'' \text{ amp.}$$
$$PF_r = \cos \diagdown 17°\ 14'\ 38'' = 95.505 \text{ lagging.}$$

The voltage consumed by the resistance and the reactance per conductor between the receiving end and the middle of the circuit is:

$$I_r\frac{R}{2} = 94.16 \times 52.5 = 4943.4 \text{ volts (resistance drop)}$$

$$I_r\frac{X}{2} = 94.16 \times 124.5 = 11{,}723 \text{ volts (reactance drop)}$$

The voltage at the middle of the circuit is from (30):

$$E_{mn} = \sqrt{(60{,}046 \times 0.95\,505 + 4{,}943.4)^2 + (60{,}046 \times 0.29\,644 + 11{,}723)^2}$$
$$= 68{,}933\underline{/25^\circ\ 21'\ 33''} \text{ volts to current vector } OP$$
$$= 68{,}933\underline{/8^\circ\ 06'\ 55''} \text{ volts to vector of reference } OR$$

The charging current consumed by the condenser (zero leakage assumed) at the middle of the circuit leads the voltage at the middle of the circuit by 90 degrees and is:

$$I_{cm} = \frac{0.001563}{1.5} \times 68{,}933 = 71.828 \text{ amp.}$$

The current per conductor for the sending-end half of the circuit may be determined as follows:

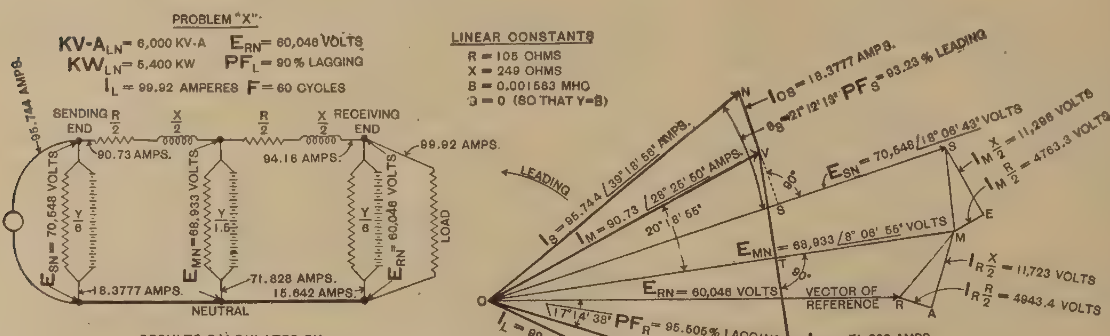
$$OT = 94.16 \times \cos\ 25^\circ\ 21'\ 33'' = 85.0867 \text{ amp.}$$
$$TP = 94.16 \times \sin 25^\circ\ 21'\ 33'' = 40.3278 \text{ amp.}$$
$$TV = 71.828 - 40.3278 = 31.5002 \text{ amp.}$$
$$I_m = \sqrt{85.0867^2 + 31.5002^2}$$
$$= 90.73\underline{/20^\circ\ 18'\ 55''} \text{ amp. to voltage vector } OM \text{ at middle.}$$
$$= 90.73\underline{/28^\circ\ 25'\ 50''} \text{ to vector of reference } OR$$

The current at the sending end of the circuit may be determined as follows:

$$OS = 90.73 \times \cos 10^\circ\ 19'\ 07'' = 89.2624$$
$$VS = 90.73 \times \sin 10^\circ\ 19'\ 07'' = 16.2516$$
$$NS = 16.2516 + 18{,}3777 = 34.6293 \text{ amp.}$$
$$I_s = \sqrt{89.2624^2 + 34.6293^2}$$
$$= 95.744\underline{/21^\circ\ 12'\ 13''} \text{ to voltage vector } OS$$
$$= 95.744\underline{/39^\circ\ 18'\ 56''} \text{ to vector of reference } OR.$$
$$Kv.a._{sn} = 95.744 \times 70.548 = 6{,}755 \text{ kv.a.}$$
$$P.F._s. = \cos\ (39^\circ 18'\ 56'' - 18^\circ\ 06'\ 43'')$$
$$= \cos\ 21^\circ\ 12'\ 13'' = 93.23 \text{ per cent leading}$$
$$Kw_{sn} = 6{,}755 \times 0.9323 = 6{,}298 \text{ kw.}$$
$$Loss_n = 6{,}298 - 5400 = 898 \text{ kw.}$$
$$\text{Eff.} = \frac{5{,}400 \times 100}{6{,}298} = 85.75 \text{ per cent}$$

Solution by Complex Quantities.—From Table Q the auxiliary constants corresponding to the three condenser method of solution are found to be:

$$a_1 = 1 - \frac{XB}{2} + \frac{B^2}{36}(X^2 - R^2) = 0.808866$$



RESULTS CALCULATED BY

RIGOROUS SOLUTION	THREE CONDENSER METHOD	% ERROR
E$_{SN}$= 70,652 VOLTS	70,548 VOLTS	- 0.15%
I$_S$= 94.75 AMPS.	95.744 AMPS.	+ 1.05%
PF$_S$= + 93.42%	+ 93.23%	- 0.21%
LOSS$_N$=855 KW	898 KW	+ 5.03%

FIG. 57.—Dr. Chas. Steinmetz's three condenser method.

The voltage consumed by the resistance and the reactance per conductor between the middle and sending end of the circuit is:

$$I_m\frac{R}{2} = 90.73 \times 52.5 = 4{,}763.3 \text{ volts (resistance drop)}$$
$$I_m\frac{X}{2} = 90.73 \times 124.5 = 11{,}296 \text{ volts (reactance drop)}$$

The voltage at the sending end from (40) is:

$$E_{sn} = \sqrt{(68{,}933 \times 0.93779 + 4{,}763.3)^2 + (68{,}933 \times 0.34719 - 11{,}296)^2}$$
$$= 70{,}548\diagdown 10^\circ\ 19'\ 07'' \text{ volts to current vector } OV$$
$$= 70.548\underline{\diagup 18^\circ\ 06'\ 43''} \text{ volts to vector of reference } OR$$

The charging current consumed by the condenser (zero leakage assumed) at the sending end of the circuit leads the voltage at the sending end by 90 degrees and is:

$$I_{cs} = \frac{0.001563}{6} \times 70{,}548 = 18.3777 \text{ amp.}$$

$$a_2 = \frac{RB}{2} - \frac{RXB^2}{18} = 0.0785091$$
$$b_1 = R - \frac{RXB}{3} = 91.3785$$
$$b_2 = X - \frac{B}{6}(X^2 - R^2) = 235.7208$$
$$c_1 = -\frac{5RB^2}{36} + \frac{RXB^3}{108} = -0.0000347$$
$$c_2 = B - \frac{5XB^2}{36} + \frac{B^3}{216}(X^2 - R^2) = +0.0014794$$

These values for the auxiliary constants are in close agreement with the rigorous values.

$$I_l\ (\cos\ \theta_l - j \sin\ \theta_l) \times (b_1 + jb_2)$$
$$= 18{,}484 + j17{,}218$$
$$E_{rn}(a_1 + ja_2) = 48{,}569 + j4{,}714$$
$$E_{sn} = 67{,}053 + j21{,}932$$
$$= 70{,}548\underline{/18^\circ\ 06'\ 43''} \text{ volts}$$

The current at the sending end is:

$$
\begin{aligned}
I_l\,(\cos\theta_l - j\sin\theta_l) \times (a_1 + ja_2) &= 76.159 - j28.170 \\
E_{rn}(c_1 + jc_2) &= -2.084 + j88.832 \\
I_s &= 74.075 + j60.662 \\
&= \underline{95.744/39^\circ\ 18'\ 56''} \text{ amp.}
\end{aligned}
$$

By comparing these results with those obtained by the impedance method of procedure, it will be seen that they are in exact agreement.

Convergent Series Expression.—Dr. F. E. Pernot in "Electrical Phenomena in Parallel Conductors," Vol. I, shows that the above described three condenser solution is equivalent to using the following values for the auxiliary constants in the convergent series form of solution:

$$A' = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{36}\right)$$

$$B' = Z\left(1 + \frac{ZY}{6}\right)$$

$$C' = Y\left(1 + \frac{5ZY}{36} + \frac{Z^2Y^2}{216}\right)$$

Comparing the above expressions for the auxiliary constants with the complete expressions yielding rigorous values, the following differences may be noted. For constant A' the first two terms are the same as in the complete series, but the third term is less than in the complete series, and all terms beyond the third are omitted. For constant B' the first two terms are the same as in the complete series, but all terms beyond the second are omitted. For constant C' both the ZY and the Z^2Y^2 terms are smaller than in the complete series and all terms beyond the third are omitted.

The above expressions yield the same values for the auxiliary constants as given in Table Q. Thus from Chart XI, the following values corresponding to problem X are taken:

$$
\begin{aligned}
ZY &= -0.389187 + j0.164115 \\
Z^2Y^2 &= +0.124532 - j0.127742
\end{aligned}
$$

Therefore

$$
\begin{aligned}
A' = \;& 1.000000 \\
& -0.194593 + j0.0820575 \\
& 0.003459 - j0.0035484 \\
\hline
A' = \;& 0.808866 + j0.0785091 \\
B' = \;& 1.000000 \\
& -0.0648645 + j0.0273525 \\
\hline
& Z(0.9351355 + j0.0273525) \\
B' = \;& 91.3785 \quad + j235.7208 \\
C' = \;& 1.000000 \\
& -0.0540538 + j0.0227938 \\
& +0.0005765 + j0.0005914 \\
\hline
& Y(0.9465227 + j0.0222024) \\
C' = \;& -0.0000347 + j0.0014794
\end{aligned}
$$

It will be seen that the above convergent series expressions for the auxiliary constants check exactly with those as determined by the equations in Table Q.

COMPARATIVE ACCURACY OF VARIOUS METHODS

In order to determine the inherent error in various methods of solution, when applied to circuits of increasing length; also for frequencies of both 25 and 60 cycles, 64 problems were solved. These problems embrace thirty-two 25-cycle circuits, varying in length from 20 to 500 miles and in voltage from 10,000 to 200,000 volts. Fixed receiving-end load conditions were assumed for unity, and also for 80 per cent power-factor lagging. These same problems were also solved for a frequency of 60 cycles.

These 64 problems with corresponding linear constants and assumed load conditions are stated on Chart XXII. This is followed by columns in which have been tabulated the error in voltage at the sending end of these circuits as determined by nine different methods. The errors are expressed in per cent of receiving-end voltage. Obviously the inherent error corresponding to various methods will vary widely for conductors of various resistances and to some extent for different receiving-end loads. The tabulated values should therefore be looked upon as comparative rather than absolute for all conditions.

Rigorous Solution.—The column headed "Rigorous Solution" contains values for the sending-end voltage which are believed to be exact. These values were obtained by calculating values for the auxiliary constants by means of convergent series and then calculating the performance mathematically. The calculations were carried out to include the sixth place and terms in convergent series were used out to the point where they did not influence the results.

The first values calculated were checked by a second set of values calculated independently at another time and where differences were found the correct values were determined and substituted. This correct list of values was again checked by a third independent calculation. It is therefore believed that the values contained in this column are exact, representing 100 per cent.

Semi-graphical Solution.—The next column contains the error in the results as derived by the combination of an exact mathematical solution for the auxiliary constants and a graphical solution from there on. This combination gave results in which the maximum error does not exceed eight one-hundredths of 1 per cent of receiving-end voltage for either frequency. In other words, since the values for the auxiliary constants used in this method were exact, the maximum error of eight one-hundredths of 1 per cent occurs in the construction and reading of the graphical constructions.

Complete Graphical Solution.—This solution employs Wilkinson's Charts for obtaining graphically the auxiliary constants, the remainder of the solution being also made graphically as previously described. It will be seen that the maximum error as obtained by this complete graphical solution is seven one-hundredths of 1 per cent for the 25 cycle and twenty-five one-hundredths of 1 per cent for the 60-cycle circuits.

CHART XXII—COMPARISON OF RESULTS BY VARIOUS METHODS

Problem No.	Length of Circuit—Miles	Conductors	Spacing in Feet—Delta	Linear Constants: R	X	B × 10^{-6}	G	Load at Receiving-End: KV-A *	E_R	E_{RN}	P F %	I_R	Rigorous Solution (These values are exact) E_{SN}	% Error in Receiving-End Voltage as Determined by: Semi-Graphical Method % Error	Complete Graphical Method % Error	H. B. Dwight's "K" Formulas % Error	Dr. Chas. P. Steinmetz's Three Condenser Method % Error	Nominal "T" or Middle Condenser Method % Error	Nominal "π" or Split Condenser Method % Error	Single End Condenser Method % Error	Impedance Method % Error
25 CYCLES																					
1	20	#0000	3	5.54	5.36	57.2	0	1,300	10,000	5,774	80	75	6,347	0	+.05	0				-.01	0
2	"	COPPER	"	"	"	"	0	"	"	"	100	"	6,202	0	+.03	0				-.01	0
3	20	#0000	3	5.54	5.36	57.2	0	5,000	20,000	11,550	80	144.4	12,653	-.04	+.06	-.01				-.02	+.02
4	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,372	-.05	+.02	-.01				-.02	+.02
5	30	#0000	4	8.31	8.5	81	0	3,500	20,000	11,550	80	101	12,733	+.02	+.06	-.02				-.03	+.04
6	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,415	+.08	+.04	-.02				-.03	+.04
7	30	#0000	4	8.31	8.5	81	0	8,000	30,000	17,320	80	154	19,125	+.05	0	-.01				-.03	+.03
8	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,640	+.08	+.05	+.01				-.02	+.03
9	50	#0000	4	13.85	14.1	135	0	5,000	30,000	17,320	80	96.2	19,184	0	-.07	+.03				-.08	+0.1
10	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,685	-.05	-.03	+.02				-.05	+0.1
11	50	#0000	6	13.85	15.1	125	0	20,000	60,000	34,640	80	192.5	38,490	-.03	-.04	+.01			0	-.08	+0.1
12	"	COPPER	"	"	"	"	0	"	"	"	100	"	37,387	-.02	-.03	+.01			0	-.07	+0.1
13	100	#0000	9	27.7	32.2	233	0	22,000	88,000	50,810	80	144.4	56,619	-.07	-.03	0		-.01	+.01	-.31	+0.3
14	"	COPPER	"	"	"	"	0	"	"	"	100	"	54,820	-.02	-.04	0		-.01	+.01	-.30	+0.3
15	100	#0000	11	27.7	33.2	226	0	40,000	120,000	69,290	80	192.5	77,147	-.02	-.06	0		-.01	+.02	-.30	+0.4
16	"	COPPER	"	"	"	"	0	"	"	"	100	"	74,642	-.02	-.03	0		-.01	+.02	-.31	+0.4
17	200	300,000 C.M.	11	39.2	64.8	464	0	25,000	120,000	69,290	80	120.3	76,754	+.06	-.01	0		-.04	+.06	-1.24	+1.4
18	"	COPPER	"	"	"	"	0	"	"	"	100	"	73,401	+.05	-.06	0		-.04	+.06	-1.24	+1.4
19	200	300,000 C.M.	17	39.2	69.2	434	0	40,000	140,000	80,830	80	165	91,761	-.02	+.05	-.08		-.05	+.06	-1.19	+1.4
20	"	COPPER	"	"	"	"	0	"	"	"	100	"	86,863	-.02	-.01	+.01		-.04	+.05	-1.19	+1.4
21	300	636,000 C.M.	11	44.1	91.2	747	0	20,000	120,000	69,290	80	96.2	75,682	0	+.02	+.05		-.09	+.15	-2.83	+3.2
22	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	71,762	+.08	-.02	+.02		-.08	+.13	-2.88	+3.2
23	300	636,000 C.M.	21	44.1	101	672	0	60,000	200,000	115,500	80	173.2	128,450	-.04	+.04	+.03		-.11	+.17	-2.74	+3.4
24	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	120,574	0	-.06	+.01		-.11	+.15	-2.82	+3.3
25	400	636,000 C.M.	17	58.8	130	928	0	20,000	140,000	80,830	80	82.5	86,404	-.05	—	+.11	0	-.19	+.26	-5.08	+5.7
26	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	81,647	-.06	—	+.05	0	-.18	+.23	-5.30	+5.7
27	400	63[illegible],000 C.M.	21	58.8	134	896	0	50,000	200,000	115,500	80	144.4	127,267	-.05	—	+.09	0	-.22	+.32	-4.80	+5.6
28	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	118,833	-.03	—	0	0	-.21	+.29	-4.89	+5.6
29	500	6[illegible]6,000 C.M.	17	73.5	163	1160	0	15,000	140,000	80,830	80	61.86	83,045	-.06	—	+.06	-0.04	-.27	+.36	-8.22	+9.2
30	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	78,658	+.05	—	+.01	-0.04	-.23	+.31	-8.32	+9.3
31	500	636,000 C.M.	21	73.5	168	112[illegible]	0	40,000	200,000	115,500	80	115.5	123,401	+.08	—	+.02	-0.04	-.40	+.50	-7.65	+9.0
32	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	115,162	+.08	—	-.02	-0.04	-.37	+.44	-5.99	+9.0
60 CYCLES																					
33	20	#0000	3	5.54	12.88	137	0	1,300	10,000	5,774	80	75	6,702	0	-.15	0				-.07	+.07
34	"	COPPER	"	"	"	"	0	"	"	"	100	"	6,259	+.06	+.02	+.02				-.06	+0.1
35	20	#0000	3	5.54	12.88	137	0	5,000	20,000	11,550	80	144.4	13,333	+.02	-.10	0				-.07	+0.1
36	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,480	+.02	+.04	0				-.07	+0.1
37	30	#0000	4	8.31	20.4	195	0	3,500	20,000	11,550	80	101	13,482	+.07	+.06	0				-.15	+0.2
38	"	COPPER	"	"	"	"	0	"	"	"	100	"	12,537	+.05	+.06	0				-.16	+0.2
39	30	#0000	4	8.31	20.4	195	0	8,000	30,000	17,320	80	154	20,268	+.03	+.06	+.01		0	0	-.15	+0.2
40	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,830	-.03	+.05	+.02		0	0	-.16	+0.2
41	50	#0000	4	13.85	34	3[illegible]4	0	5,000	30,000	17,320	80	96.2	20,331	0	+.04	+.03		-.02	+.04	-.42	+0.5
42	"	COPPER	"	"	"	"	0	"	"	"	100	"	18,845	+.08	-.03	-.02		-.02	+.03	-.44	+0.5
43	50	#0000	6	13.85	36.4	301	0	20,000	60,000	34,640	80	192.5	40,976	+.03	-.01	+.02		-.02	+.03	-.41	+0.5
44	"	COPPER	"	"	"	"	0	"	"	"	100	"	37,773	+.04	-.01	+.03		-.02	+.04	-.42	+0.5
45	100	#0000	9	27.7	77.4	5[illegible]2	0	22,000	88,000	50,810	80	144.4	59,925	+.03	-.09	+.08	0	-.08	+.13	-1.61	+1.91
46	"	COPPER	"	"	"	"	0	"	"	"	100	"	54,869	0	-.13	+.05	0	-.07	+.13	-1.69	+1.96
47	100	#0000	11	27.7	79.7	542	0	40,000	120,000	69,290	80	192.5	81,710	-.08	-.06	-.02	0	-.08	+.14	-1.60	+1.84
48	"	COPPER	"	"	"	"	0	"	"	"	100	"	74,735	-.05	-.11	+.01	0	-.07	+.12	-1.68	+1.92
49	200	300,000 C.M.	11	39.2	156	1116	0	25,000	120,000	69,290	80	120.3	79,000	+.03	+.14	+.18	-0.04	-.46	+.61	-6.53	+7.8
50	"	COPPER	"	"	"	"	0	"	"	"	100	"	70,599	+.08	+.07	+.14	-0.04	-.39	+.47	-6.99	+8.1
51	200	300,000 C.M.	17	39.2	166	1044	0	40,000	140,000	80,830	80	165	96,727	-.07	+.14	+.22	-0.04	-.51	+.73	-5.96	+7.5
52	"	COPPER	"	"	"	"	0	"	"	"	100	"	84,862	+.07	+.02	+.25	-0.04	-.45	+.62	-6.37	+7.8
53	300	636,000 C.M.	11	44.1	220	1794	0	20,000	120,000	69,290	80	96.2	72,747	-.04	+.05	+.46	-0.21	-1.51	+1.34	-15.68	+19
54	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	63,810	-.02	+.21	-.25	-0.21	-1.34	+1.01	-16.43	+20
55	300	636,000 C.M.	21	44.1	243	1614	0	60,000	200,000	115,500	80	173.2	126,541	-.05	+.25	+.46	-0.21	-1.60	+1.60	-14.50	+18
56	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	109,189	-.07	+.15	+.51	-0.21	-1.44	+1.29	-15.12	+19
57	400	636,000 C.M.	17	58.8	314	2212	0	20,000	140,000	80,830	80	82.5	74,182	+.01	—	-.08	-0.71	-3.92	+2.15	-29.34	+37
58	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	64,377	+.03	—	.0	-0.71	-3.65	+1.74	-27.16	+39
59	400	636,000 C.M.	21	58.8	322	2152	0	50,000	200,000	115,500	80	144.4	113,606	-.08	—	-.49	-0.75	-4.11	+2.99	-25.82	+35
60	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	96,987	+.01	—	+1.04	-0.81	-3.92	+2.84	-22.38	+36
61	500	636,000 C.M.	17	73.5	390	2785	0	15,000	140,000	80,830	80	61.86	59,046	+.06	—	-1.47	-1.97	-9.18	+2.28	-40.82	+70
62	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	51,327	+.06	—	+.25	-1.89	-8.64	+2.54	-20.62	+73
63	500	[illegible] C.M.	21	73.5	402	2690	0	40,000	200,000	115,500	80	115.5	93,725	+.06	—	-.28	-1.84	-9.32	+4.44	-35.54	+64
64	"	ALUMINUM	"	"	"	"	0	"	"	"	100	"	80,106	+.06	—	+3.8	-1.72	-8.84	+5.43	-13.53	+65

*It would be commercially impractical to transmit such small amounts of power some of the extreme distances indicated by the tabulation. The problems are stated simply for the purpose of illustrating in an approximate manner the effect distance of transmission has upon the voltage drop as calculated by various methods.

These errors represent the combined result of various errors. First there is a slight fundamental error in the basis upon which the Wilkinson Charts are constructed when used for circuits employing conductors of various sizes and spacings, the introduction of this error making possible the simplification attained. Then there is the inherent limitation of precision obtainable in the construction and reading of the charts and vector diagrams.

These results show that the inherent accuracy of this simplified, all graphical solution is sufficiently accurate for all practical power circuits up to 300 miles long.

Dwight's "K" Formulas.—The high degree of accuracy resulting by the use of H. B. Dwight's "K" formulas should be noted. This error is a maximum of eleven one-hundredths of 1 per cent for these 32 25-cycle problems. The statement is therefore justified that these "K" formulas are sufficiently accurate for all 25-cycle power circuits.

For the 60-cycle problems the maximum error by the "K" formulas for problems up to and including 200 miles is one-fourth of 1 per cent of receiving-end voltage. For 300-mile circuits this error is one-half of 1 per cent and increases rapidly as the circuit exceeds 300 miles in length. The accuracy of the "K" formulas for 60-cycle circuits is therefore well within that of the assumed values of the linear constants for circuits up to approximately 300 miles in length.

The "K" formulas are based upon the hyperbolic formula expressed in the form of convergent series. In the development of these formulas, use was made of the fact that the capacitance multiplied by the reactance of non-magnetic transmission conductors is a constant quantity to a fairly close approximation. This assumption has enabled the "K" formulas to be expressed in comparatively simple algebraic form without the use of complex numbers To those not familiar or not in position to make themselves familiar with the operation of complex numbers, such as is used in the convergent series or hyperbolic treatments, the availability of the Dwight "K" formulas will be apparent.*

Localized Capacitance Methods.—The next four columns contain values indicating the error in results as determined by the four different localized capacitance methods previously described in detail. It is interesting to note the high degree of accuracy inherent in Dr. Steinmetz's three condenser method. It is also interesting to note that three of these methods over compensate (that is, give receiving-end voltages too low) and one (the split condenser method) gives under compensation.

Impedance Method.—The values of the sending-end voltage as obtained by the impedance method (which takes no account of capacitance) are always too high when applied to circuits containng capacitance. The results by this method are included here simply to serve as an indication of how great is the error for this method when applied to circuits of various lengths and frequencies of 25 and 60 cycles. Some engineers prefer to use this method for circuits of fair length and allow for the error. These tabulations will give an approximation of the necessary allowance to be made.

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* These have been included with much other valuable material by H. B. Dwight: "Transmission Line Formulas," D. Van Nostrand Co., New York City.

CHAPTER XII

SYNCHRONOUS MACHINES FOR POWER-FACTOR AND VOLTAGE CONTROL

SYNCHRONOUS CONDENSERS AND PHASE MODIFIERS

The term "synchronous condenser" applies to a synchronous machine for raising the power-factor of circuits. It is simply floated on the circuit with its fields over excited so as to introduce into the circuit a leading current. Such machines are usually not intended to carry a mechanical load. When this double duty is required they are referred to as synchronous motors for operation at leading power-factor. On long transmission circuits, where synchronous condensers are used in parallel with the load for varying the power-factor, thereby controlling the transmission voltage, it is sometimes necesary to operate them with under-excited fields at periods of lightloads. They are then no longer synchronous condensers but strictly speaking become synchronous reactors.

Whether synchronous motors for operation at leading power-factor, synchronous condensers or synchronous reactors be used they virtually do the same thing, that is; their function is to change the power-factor of the load by changing the phase angle between the armature current and the terminal voltage. They are, therefore, sometimes referred to as "phase modifiers." This latter name seems more appropriate when the machine is to be operated both leading and lagging, as when used for voltage control of long transmission lines.

Table *R*.—Synchronous Condenser Losses

Kv.a.	Loss(kw.)	Kv.a.	Loss (kw.)
100	10	3,000	100
200	15	5,000	150
300	20	7,500	250
500	30	10,000	270
750	40	15,000	420
1,000	49	20,000	450
1,500	65	25,000	600
2,000	80	35,000	900
2,500	90	50,000	1,250

Rating.—Synchronous condensers as regularly built may be operated at from 30 to 40 per cent of their rating lagging, depending upon the individual design. Larger lagging loads result in unstable operation on account of the weakened field. Phase modifiers can be designed to operate at full rating, both leading and lagging, but they are larger, require larger exciters, have a greater loss and cost 15 to 20 per cent more than standard condensers.

Starting.—Condensers are furnished with squirrel-cage damper windings, to prevent hunting, which also provides a starting torque of approximately 30 per cent of normal running torque. They have a pull-in torque of around 15 per cent of running torque. The line current at starting varies from 50 to 100 per cent of normal. The larger units are sometimes equipped for forced oil lubrication, which raises the rotor sufficiently to permit of oil entering the bearing, thus reducing the starting current.

Mechanical Load.—Synchronous condensers are generally built for high speeds and equipped with shafts of small diameter. If they are to be used to transmit some mechanical power it may be necessary to equip them with larger shafts and bearings, particularly if belted rather than direct connected. If a phase modifier is to furnish mechanical energy and at the same time to operate lagging at times of light load for the purpose of holding down the voltage on an unloaded transmission line there may be danger of the machine falling out of step, if a heavy mechanical load occurs when the machine is operating with a weak field.

Losses.—At rated full load leading power-factor the total losses, including those of the exciter, will vary from approximately 10 per cent for the smallest capacity to approximately 2.5 per cent for the larger capacity 60-cycle synchronous condensers. The approximate values given in Table *R* may be of service for preliminary purposes.

"V" Curves.—The familiar *V* curves shown in Fig. 63 serve to give some idea of the variation in field current for a certain phase modifier when operating between full load lagging and full load leading kv.a.* For this particular machine the excitation must be increased from 112 amp. at no load minimum input or unity power-factor to 155 amp. at full kv.a. output leading or a range of 1.4 to 1 in field excitation. For operation between full lagging and full leading, with no mechanical work done, the range of excitation is from 67 to 155 or 2.3 to 1.

Generators as Condensers.—Ordinary alternators may be employed as synchronous condensers or synchronous motors by making proper changes in their field poles and windings to render them self-starting and safely insulated against voltages induced in the field when starting.

Where transmission lines feed into a city net work and a steam turbine generator station is available these generating units can serve as synchronous condensers

* These curves have been reproduced from H. B. Dwight: "Constant Voltage Transmission."

by supplying just enough steam to supply their losses and keep the turbine cool. When operated in this way they make a reliable standby to take the important load quickly in case of trouble on a transmission line.

Location for Condensers.—The nearer the center of load that the improvement in power-factor is made the better, as thereby the greatest gain in regulation, greatest saving in conductors and apparatus are made since distribution lines, transformers, transmission lines lines and generators will all be benefited.

How High to Raise the Power-factor.—Theoretically for most efficient results the system power factor should approach unity. The cost of synchronous apparatus having sufficient leading current capacity to raise the power-factor to unity increases so rapidly as unity is approached, as to make it uneconomical to carry the power-factor correction too high. Not only the cost but also the power loss chargeable to power-factor improvement mounts rapidly as higher power-factors are reached. This is for the reason that the reactive kv.a. in the load corresponding to each per cent change in power-factor is a maximum for power-factors near unity. It usually works out that it doesn't pay to raise the power-factor above 90 to 95 per cent, except in cases where the condenser is used for voltage control, rather than power-factor improvement.

DETERMINING THE CAPACITY OF SYNCHRONOUS MOTORS AND CONDENSERS FOR POWER-FACTOR IMPROVEMENT

A very simple and practical method for determining the capacity of synchronous condensers to improve the power-factor is by aid of cross-section paper. A very desirable paper is ruled in inch squares, sub-ruled into 10 equal divisions. With such paper, no other equipment is required.

With a vector diagram it is astonishing how easy it is to demonstrate on cross-section paper, the effect of any change in the circuit. A few typical cases are indicated in Fig. 64. These diagrams are all based upon an original circuit of 3,000 kv.a. at 70 per cent power-factor lagging, shown by (1). It is laid off on the cross-section paper as follows. The power of the circuit is 70 per cent of 3,000 or 2,100 kw. which is laid off on line AB, by counting 21 sub-divisions, making each sub-division represent 100 kw. or 100 kv.a. Now lay a strip of blank paper over the cross-section paper and make two marks on one edge spaced 30 sub-divisions apart. This will then be the length of the line AC. This blank sheet is now laid over the cross section paper with one of the marks at the edge held at the point A. The other end of the paper is moved downward until the second mark falls directly below the point B thus locating point C. The length of the line BC represents the lagging reactive kv.a. in the circuit, in this case 2,140 kv.a.

Diagram (2) shows the effect of adding a 1,500 kv.a. synchronous condenser to the original circuit. The full load loss of this condenser is assumed as 70 kw. The resulting kv.a. and power-factor are determined as follows: Starting from the point C trace to the right a line 0.7 of a division long. This is parallel to the line AB for the reason that it is true power, so that there is now 2,170 kw. true energy. The black triangle represents the condenser, the line CD, 15 divisions long, representing the rating of the condenser. In this case, however, the vertical line is traced upward in place of downward, because the condenser kv.a. is leading. This condenser results in decreasing the load from 3,000 kv.a. at 70 per cent power-factor to 2,275 kv.a. at 95.4 per cent power-factor. The line AD represents in magnitude and direction, the resulting kv.a. in this circuit. The power-factor of the resulting circuit is the ratio of the true energy in kw. to the kv.a. or 95.4 per cent, in this case. Since the line AD lays below the line AB, that is in the lagging direction, the power-factor is lagging.

Diagram (3) is the same as (2) except that the condenser is larger, being just large enough to neutralize all of the lagging component of the load, resulting in a final load of 2,215 kw. at 100 per cent power-factor. Diagram (4) is similar to (3) except that a still larger

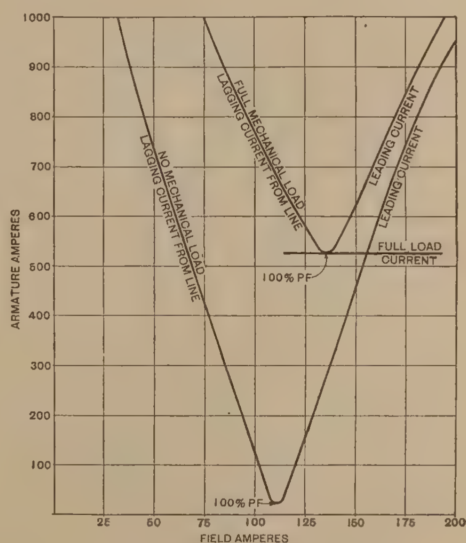


FIG. 63.—V-curves of a phase modifier.

condenser is shown. This condenser not only neutralizes all of the lagging kv.a. of the load but in addition introduces sufficient leading kv.a. into the circuit to give a leading resultant power-factor of 94 per cent with an increase in kv.a. of the resulting circuit from 2,215 of (3) to 2,400 kv.a. of (4).

Diagram (5) illustrates the addition to the original circuit of a 100 per cent power-factor synchronous motor of 600 hp. rating. As this motor has no leading or lagging component, there is no vertical projection. The power-factor of the circuit is raised from 70 to 77 per cent as the result of the addition of 500 kw. true power (load plus loss in motor) to the circuit. A resistance load would have this same effect.

Diagram (6) shows a 450 kw. (600 hp.) synchronous motor of 625 kv.a. input at 80 per cent leading power-factor added to the original circuit. The input to this motor (including losses) is assumed to be 500 kw. The resulting load for the circuit is 3,150 kv.a. at 82.5 per cent lagging power-factor.

The Diagram (7) shows an 850 kw. (1,140 hp.) synchronous motor generator of 1,666 kv.a. input at 60

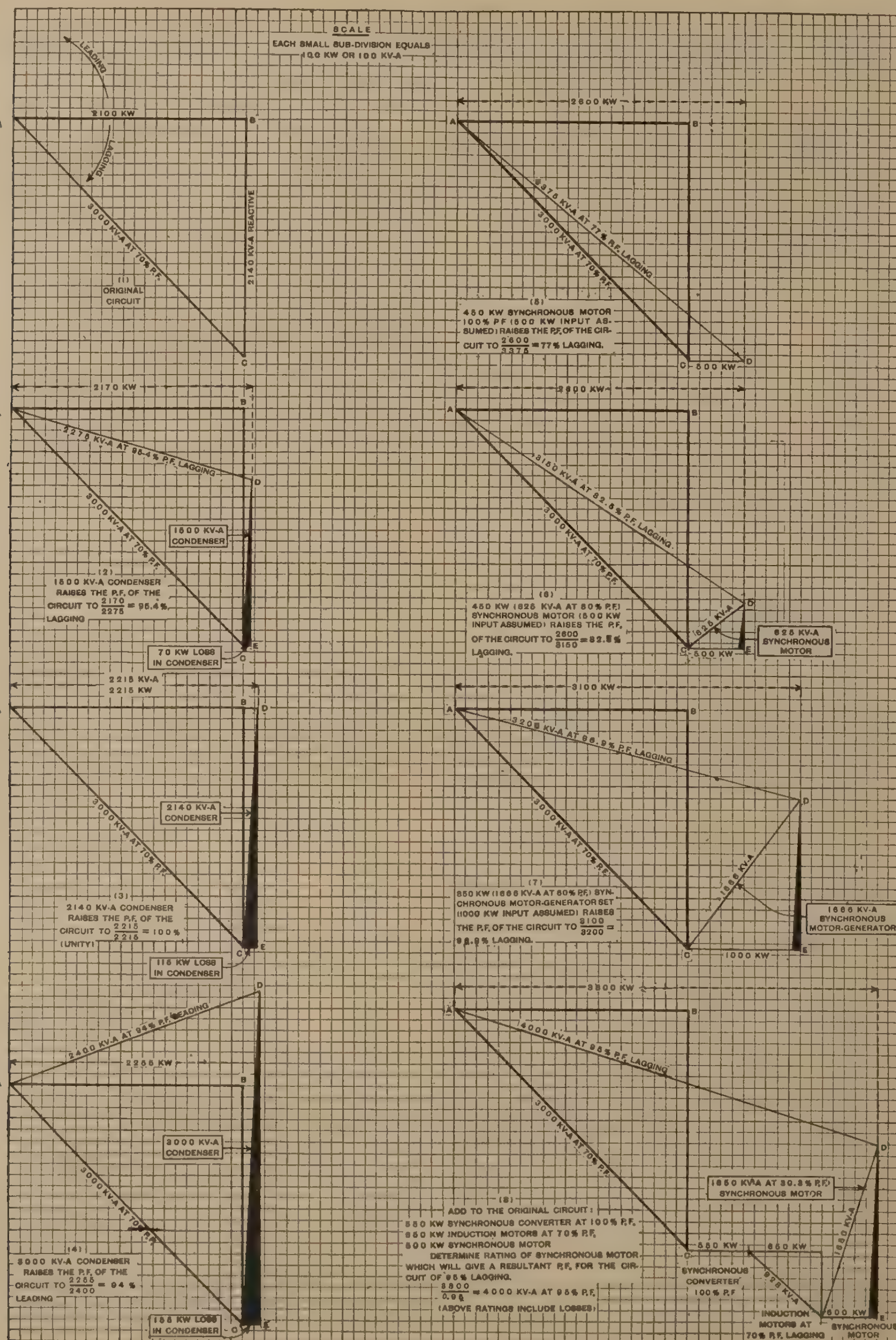


Fig. 64.—Examples in power-factor improvement.

per cent power-factor leading added to the original circuit. This gives a resulting load of 3,200 kv.a. at 96.9 per cent lagging power-factor.

Diagram (8) shows the addition to the original circuit of the following loads, including losses.

- A 550 kw. synchronous converter at 100 per cent power-factor.
- A 650 kw. induction motor at 70 per cent lagging power-factor.
- A 500 kw. synchronous motor.

The resultant load of this circuit is 3,800 kw. and if a power-factor of 95 per cent lagging is desired the total kv.a. will be 4,000. The line AD may be located by a piece of marked paper and the capacity of the necessary synchronous motor scaled off. This is found to be 1,650 kv.a. at 30.3 per cent power-factor.

The Circle Diagram.—The circle diagram in Fig. 65 shows the fundamental relations between true kw. reactive kv.a. and apparent kv.a. corresponding to different power-factors, the values upon the chart being read to any desired scale to suit the numerical values of the problem under consideration. This diagram is sufficiently accurate for ordinary power-factor problems. In place of drawing out the vector diagrams as just explained they are traced out with a pin point on the circle diagram.

Assume again a load of 2,100 kw. at 70 per cent power-factor lagging, and that the power-factor is to be raised to 95.4 per cent as in (2) of Fig. 64, and that the loss in the condenser necessary to accomplish this is again taken as 70 kw. The capacity of the synchronous condenser may be traced on the circle diagram as follows: From the true power load of 2,100 kw. (top horizontal line) follow vertically downward until the diagonal line representing 70 per cent power-factor is reached. This is opposite 2,140 kv.a. reactive component. From the point thus obtained, go horizontally to the right a distance representing 70 kw. power. From this point go vertically upward until the diagonal line representing 95.4 per cent power-factor is reached. Then read the amount of reactive kv.a. (640) corresponding to this last point. The original lagging component of 2,140–640 = 1,500 kv.a. which is approximately the capacity of the condenser necessary to accomplish the above results. Actually the rating of the condenser would be the hypotenuse rather than the vertical projection. The error in assuming the vertical projection as the rating of the condenser is negligible unless the condenser furnishes mechanical power, in which case the hypotenuse should be marked on a separate strip of paper and its length determined from the kv.a. scale. The accompanying chart for determining the reactive kv.a. will be found very useful in this connection.

ADVANTAGE OF HIGH POWER-FACTOR

Less Capacity Installed.—Low power-factors demand larger generators, exciters, transformers, switching equipment and conductors. Loads of 70 per cent power-factor demand equipment of 28 per cent greater capacity than would be required if the power-factor were 90 per cent. The cost of apparatus for operation at 70 per cent power-factor would be approximately 15 per cent greater than the cost of similar apparatus for 90 per cent power-factor operation, since the capacity of apparatus to supply a certain amount of energy is inversely proportional to the power-factor.

Higher Efficiency.—Assume that the power-factor of a 1,000 kv.a. (700 kw. at 70 per cent power-factor) transmission circuit is raised to 90 per cent. As the copper loss varies as the square of the current, raising the power-factor reduces the copper loss approximately 40 per cent. If we assume an efficiency for the generator of 93 per cent (1 per cent copper loss); for combined raising and lowering transformers 94 per cent (3 per cent copper loss) and for the transmission line 92 per cent, the saving in copper loss corresponding to 90 per cent power-factor operation would be as follows:

Generators	0.4 per cent
Transformers	1.2 per cent
Transmission line	3.2 per cent
Total	4.8 per cent or approximately 33 kw.

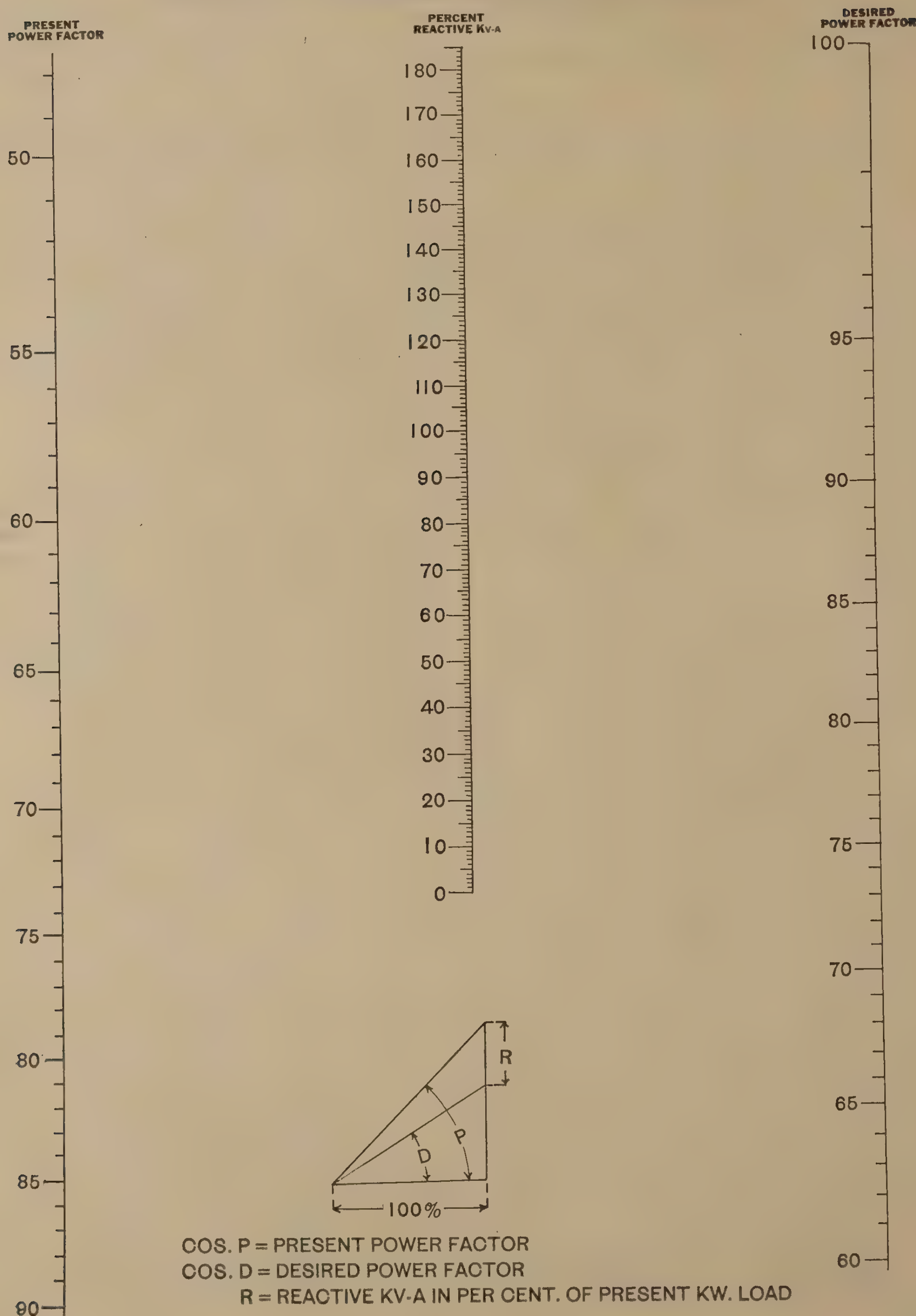
To raise the power-factor to 90 per cent would require a synchronous condenser of 375 kv.a. capacity. This size condenser would have a total loss of about 30 kw. resulting in a net gain in loss reduction of 3 kw. Against this gain would be chargeable, the interest and depreciation of the condenser cost with its accessories, also any cost of attendance which there might be in connection with its operation. It is evident that in this case it would not pay to install a condenser if increased efficiency were the only motive.

Table *S*.—Cost of Power-factor Correction with Synchronous Motors

Syn. motor kv.a.	Motor will furnish		Chargeable to power-factor correction	
	Mech. kw.	Leading kv.a.	Loss kw.	Difference in price
140	100	100	1.6	$ 500.00
280	200	200	2.5	500.00
420	300	300	5.0	500.00
700	500	500	8.0	800.00
1,050	750	750	9.0	1,000.00
1,400	1,000	1,000	14.0	1,200.00

The improvement in power-factor can be more cheaply and efficiently obtained by the installation of one or more synchronous motors designed for operation at leading power-factor. Sufficient capacity of these will give, in addition to mechanical load, sufficient leading current to raise the power-factor to 90 per cent. The extra expense and increased loss of synchronous motors enough larger to furnish the necessary leading component for power-factor correction is very small. Table *S* gives in a very approximate way, some idea of the amount of loss and proportional

CHART FOR DETERMINING THE REACTIVE KV.-A.



COS. P = PRESENT POWER FACTOR
COS. D = DESIRED POWER FACTOR
R = REACTIVE KV-A IN PER CENT. OF PRESENT KW. LOAD

cost of synchronous motors chargeable to power-factor improvement when delivering both mechanical power and leading current.

Thus if a synchronous condenser is used on the above circuit there is a loss of 30 kw. chargeable to power-factor improvement, whereas if a synchronous motor of sufficient capacity (530 kv.a.), to give 375 kw. mechanical work and at the same time the necessary 375 kv.a. leading current for power-factor improvement, the extra loss chargeable to power-factor improvement would be something like 6 kw. The increased cost of a synchronous motor to furnish 375 kv.a. leading current in addition to 375 kw. power would be about $600 whereas the cost of a 375 kv.a. condenser would be down. Table *T* gives an idea of the variation in voltage drop corresponding to various power-factors at 60 cycles.

TABLE *T*.—EFFECT OF POWER-FACTOR ON VOLTAGE DROP

Per cent power-factor	100	90	80	70
Generators* (older design)	8.0	....	25.0	
Transformers	1.2	4.1	4.9	5.5
Transmission line	7.9	13.0	14.2	15.2

* The present-day design of maximum rated generators with a short-circuit ratio of about unity will barely circulate full load current with normal no load excitation. Under such conditions the terminal voltage would be practically zero regardless of the power factor.

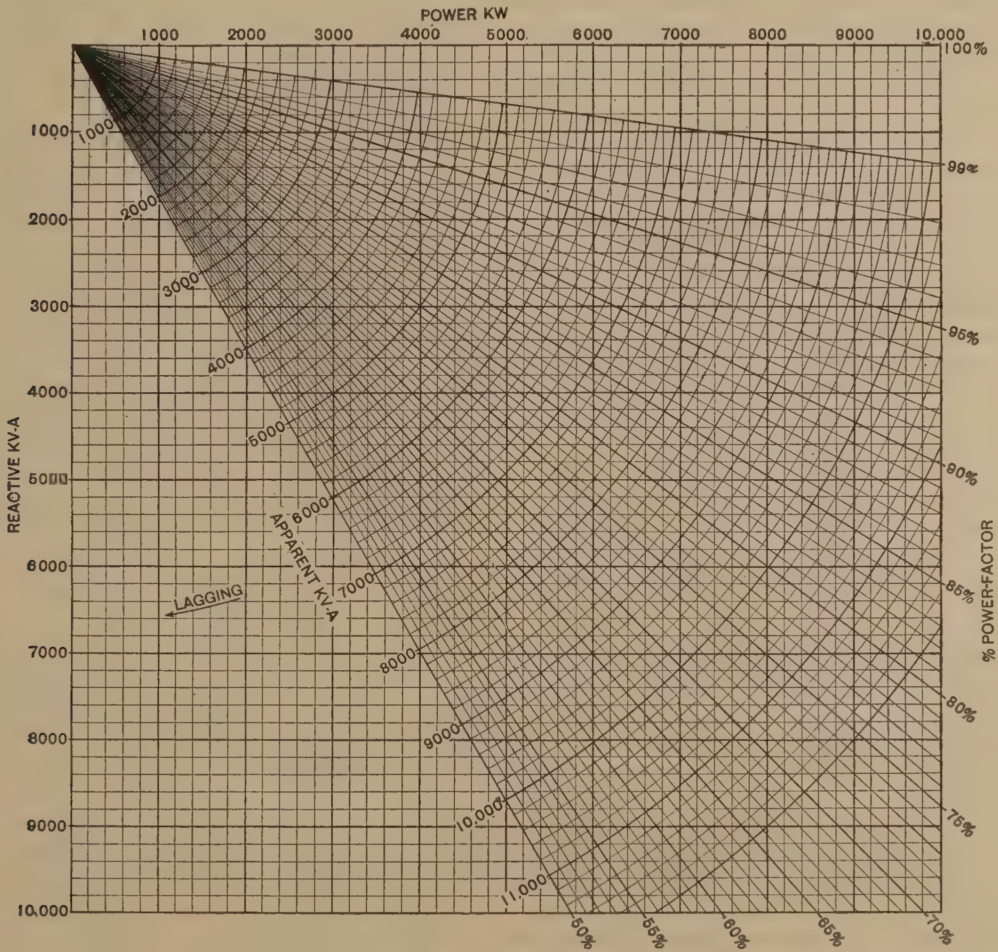


FIG. 65.—Relation between energy load, apparent load and reactive kv.a. for different power factors.

in the neighborhood of $4,000. Varying costs and designs make cost and loss values unreliable. They are given here only to illustrate the points which should be considered when considering synchronous motors *vs.* synchronous condensers.

Improved Voltage Regulation.—The voltage drop under load for generators, transformers and transmission lines rapidly increases as the power-factor goes down.

Automatic voltage regulation may be used to hold the voltage constant at the generators or at some other point, but it cannot prevent voltage changes at all points of the system.

Increased Plant Capacity.—The earlier alternators were designed for operation at 100 per cent power-factor with prime movers, boilers, etc., installed on the same basis. Increasing induction motor loads have

resulted in power-factors of 70 and 80 per cent. As a result, some of the older generating stations are being operated with prime movers, boilers etc. underloaded because the 100 per cent power-factor generators which they drive limit the amount of power that can be generated without endangering the generator windings. This condition some times makes it necessary to operate three units, where two might be sufficient to carry the load at unity power-factor. The shutting down of a unit would result in a considerable saving in steam consumption. A recent case came up of a transmission line 30 miles long, fed at each end by a small generating station. On account of heavy line drop it was necessary to operate both stations to furnish the comparatively light night load. Investigation developed that by installing a synchronous condenser at one of these terminal stations for reducing the voltage drop in the line, one generating station could be shut down during the night, thereby resulting in a very large annual saving in coal and labor bills.

A station may have some generating units designed for 100 per cent power-factor and other units designed for 80 per cent power-factor; or again, where two generating stations feed into the same transmission system, one may have 100 per cent power-factor generating units and the other 80 per cent power-factor generating units. In such cases, the field strength of the generators may be so adjusted as to cause the 80 per cent power-factor units to take all the lagging current, thus permitting the 100 per cent power-factor units to be loaded to their full kw. rating.

PHASE MODIFIERS FOR VOLTAGE CONTROL

With alternating-current transmission there is a voltage drop resulting from the resistance of the conductors, which is in phase with the current. In addition there is a reactance voltage drop; that is a voltage of self-induction generated within the conductors which varies with and is proportional to the current, and may add to or decrease the line voltage. If the line is long, the frequency high or the amount of power transmitted large, this induced voltage will be large, influencing greatly the line drop. By employment of phase modifiers the phase or direction of this induced voltage may be controlled to that it will be exerted in a direction that will result in the desired sending-end voltage.

A certain amount of self-induction in a transmission circuit is an advantage, allowing the voltage at the receiving end to be held constant under changes in load by means of phase modifiers. It may even be made to reduce the line voltage drop to zero, so that the voltage at the two ends of the line is the same for all loads. Self-induction also reduces the amount of current which can flow in case of short-circuits, thus tending to reduce mechanical strains on the generator and transformer windings, and making it easier for circuit breaking devices to function successfully. On the other hand, high self-induction reduces the amount of power

TABLE U.—INSTALLATIONS OF LARGE PHASE MODIFIERS 1925
By American Manufacturers

Kv. a.	R.p.m.	Volts	Cycles	No. of units	Name and location
40,000	600	11,500	60	1	Mt. Shasta Power Corp., Vacaville, Calif.
30,000	600	11,000	60	..	Great Western Power Co., San Francisco, Calif.
30,000	600	6,600	50	2	Southern California Edison Co., Laguna Belle, Calif.
30,000	600	6,600	50	1	Southern California Edison Co., Eagle Rock, Calif.
25,000	600	6,600	60	..	Dept. of Public Service, Los Angeles, Calif.
25,000	600	11,000	60	2	Nippon Elec. Power Co., Japan.
20,000	600	11,000	60	2	Mt. Shasta Power Corp., Hartley, Calif.
15,000	600	18,000	50	1	Southern California Edison Co., Los Angeles, Calif.
15,000	600	18,000	50	1	Southern California Edison Co., Vernon, Calif.
15,000	600	11,000	50	1	Takata & Co., Japan.
15,000	600	11,000	60	..	Great Western Power Co., San Francisco, Calif.
15,000	600	13,200	60	1	Utica Gas & Elec. Co., Utica, N. Y.
15,000	600	6,600	50	2	Midi Railways, France.
15,000	600	6,600	50	..	Victorial Electricity Com., Melbourne, Australia.
15,000	600	6,600	60	1	Ohio River Edison Co., Boardman, Ohio.
15,000	600	11,000	60	3	Daido Elec. Light & Power Co., Japan.
15,000	600	11,000	50	..	Keihin Denryokn K. K., Japan.
15 000	600	11,000	50	2	Tokio Elec. Lt. & Power Co., Japan.
15,000	600	6,600	60	..	Phoenix Utility Co., Terminal, Utah.
15,000	450	6,600	60	1	City of Seattle, Seattle, Wash.
15,000	720	11,000	60	..	Pacific Gas & Elect. Co., San Francisco, Calif.
15,000	375	6,600	50	1	Pacific Gas & Elec. Co., Big Creek, Calif.
12,500	720	13,200	60	1	Indiana Elec. Corp., Lenoré, Ind.
12,500	720	13,200	60	1	Indiana Elec. Corp., Indianapolis, Ind.
12,500	720	13,200	60	1	Alabama Power Co., Leeds, Ala.
12,500	600	13,800	60	..	Pacific Gas & Elect. Co., San Francisco, Calif.
10,000	720	13,800	60	1	Conn. Lt. & Pr. Co., Waterbury, Conn.
10,000	720	13,800	60	1	Blackstone Valley Gas & Elec. Co., Woonsocket, R. I.
10,000	720	13,800	60	..	Turners Falls Pr. & Engr. Co., Greenfield, Mass.
10,000	720	12,000	60	1	Western States Gas & Elec. Co., Stockton, Calif.
10,000	720	11,000	60	2	Takata & Co., Japan.
10,000	720	13,200	60	1	Union Gas & Elect. Co., Elwood Place, Ohio.
10,000	720	11,000	60	1	Portland Rwy. & Lt. Co., East St. Johns, Ore.
10,000	600	11,000	50	1	Southern California Edison Co., Colton, Calif.
10,000	600	15,000	50	1	Southern California Edison Co., Paulerino, Calif.
10,000	600	11,000	50	1	Southern California Edison Co., Katella, Calif.
10,000	600	6,600	60	..	Cie Francaise Thompson-Houston, France.

which may be transmitted over a line and may, in case of lines of extreme length, make it necessary to adopt a lower frequency. It also increases the capacity of phase modifiers necessary for voltage control. High reactance also increases the surge over-voltage that a given disturbance will set up in the system.

On the long lines, the effect of the distributed leading charging current flowing back through the line induc-

tance is to cause, at light loads, a rise in voltage from generating to receiving end. At heavy loads, the lagging component in the load is usually sufficient to reverse the low-load condition; so that a drop in voltage occurs from generating to receiving end. The charging current of the line is, to a considerable extent, an advantage; for it partially neutralizes the lagging component in the load, thus raising the power-factor of the system and reducing the capacity of synchronous condensers necessary for voltage control.

The voltage at the receiving end of the line should be held constant under all loads. To partially meet this condition, the voltage of the generators could be varied to a small extent. On the longer lines, however, the voltage range required of the generators would be too great to permit regulation in this manner. In such cases, phase modifiers operating in parallel with the load are employed. The function of phase modifiers is to rotate the phase of the current at the receiving end of the line so that the self-induced voltage of the line (always displaced 90 degrees from the current) swings around in the direction which will result in the desired line drop. In some cases a phase modifier is employed which has sufficient capacity not only to neutralize the lagging component at full load, but, in addition, to draw sufficient leading current from the circuit to compensate entirely for the ohmic and reactance voltage drops of the circuit. In this case, the voltage at the two ends of the line may be held the same for all loads. This is usually accomplished by employing an automatic voltage regulator which operates on the exciter fields of the phase modifier. The voltage regulator may, if desired, be arranged to compound the substation bus voltage with increasing load.

CHECKING THE WORK

A most desirable method of determining line performance is by means of a drawing board and an engineer's scale. A vector diagram of the circuit under investigation, with all quantities drawn to scale, greatly simplifies the problem. Each quantity is thus represented in its true relative proportion, so that the result of a change in magnitude of any of the quantities may readily be visualized. Graphical solutions are more readily performed, and with less likelihood of serious error than are mathematical solutions. The accuracy attainable when vector diagrams are drawn 20 to 25 in. long and accurate triangles, T squares, straight edges and protractors are employed is well within practical requirements. Even the so-termed "complete solution" may be performed, graphically with ease and accuracy. A very desirable virtue of the graphical solution which follows is that it exactly parallels the fundamental, mathematical solution. For this reason this graphical solution is most helpful even when the fundamental mathematical solution is used, for it furnishes a simple check against serious errors. The result may be checked graphically after each individual mathematical operation by drawing a vector in the diagram paralleling the mathematical operation. Thus, any serious error in the mathematical solution may be detected as soon as made.*

When converting a complex quantity mathematically from polar to rectangular co-ordinates, or *vice versa*, the results may readily be checked by tracing the complex quantity on cross-section paper and measuring the ordinates and polar angle, or for approximate work the conversion may be made graphically to a large scale. For instance, in using hyperbolic functions, polar values will be required for obtaining powers and roots of the complex quantity. For approximate work much time will be saved by obtaining the polar values graphically.

In the graphical solution of line performance it will usually be desirable to check the line loss by a mathematical solution in cases which require exact loss values. Since the line loss may be 5 per cent or less of the energy transmitted, a small error in the overall results might correspond to a large error in the value of the line loss.

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*A method of checking arithmetical operations which requires little time and is an almost preventative of errors is that known as "casting out the nines." This method is given in most older arithmetics but has been dropped from many of the modern ones. A complete discussion is given in Robinson: "New Practical Arithmetic" by The American Book Co.

CHAPTER XIII

EFFECT OF TRANSFORMERS IN THE CIRCUIT

In the foregoing discussions no account has been taken of the voltage drop through transformers. Transmission circuits usually have lowering transformers connected between them and the receiving-end load and usually there are also transformers in the sending-end of the transmission circuit.

The inductance and capacitance of a transformer are not distributed in the same manner as those of the transmission circuit to which the transformer may be connected. It is difficult to take into exact account the effect of the transformers, but for practical purposes of power transmission circuits it will usually be sufficient to ignore the effect of the comparatively small capacitance of the transformer windings, but to take account of the reactance of the transformers in the following manner.

As an illustration, assume that problem X contains a bank of transformers (or one three-phase transformer) of 18,000 kv.a. total capacity at each end of the circuit, and that it is desired to take into account the effect of these transformers upon the voltage regulation between the generator bus and the receiving-end load. The raising and lowering transformers will be considered as a part of the transmission circuit, and their resistance and their reactance added to that of the transmission conductors. The calculation will be made in terms of the high-tension circuit. If results are desired in terms of the low voltage side of the transformers, they may be obtained from the ratio of transformation. The connection of the transformers is immaterial, as the results will be the same whether star or delta connection is assumed.

Table M indicates approximately the variation in the values of the resistance and the reactance volts for 25 and 60 cycle transformers corresponding to units of various capacities. Since the performance of transformers, as applied to specific cases, may vary greatly from these tabular values, it will be desirable in each case, where the transformers are included in the calculations, to obtain the exact performance of the transformers. In order to illustrate the application of the Peter's efficiency chart, it will be assumed that in this case only the efficiency and the regulation of the transformers are known. We will assume also that the transformers will be 18,000 kv.a., three-phase, and that one will be installed at each end of the circuit. Required to find the resistance and the reactance (in ohms) per transformer to neutral. The assumed performance is as follows:

Efficiency at full load = 98.28 per cent.
Efficiency at one-fourth load = 96.98 per cent.
Regulation at 100 per cent power-factor = 1.15 per cent.
Regulation at 80 per cent power-factor = 3.74 per cent.

By laying a straight edge across the two known efficiency points on the chart, the iron and copper losses expressed in per cent of full load kv.a. of 0.72 per cent and 1.05 per cent respectively may be read directly from the chart.

The exact values for the iron and copper loss may, if desired, be calculated by the following simple algebraic, procedure. At full load the input is—

$$\frac{18{,}000{,}000}{0.9828} = 18{,}315{,}020 \text{ watts}$$

so that the total loss at full load is 315,020 watts.

At one fourth load the input is,

$$\frac{4{,}500{,}000}{0.9698} = 4{,}640{,}130 \text{ watts}$$

so that the total loss is 140,130 watts.
Then let

$$x = \text{the iron loss at all loads}$$

and

$$y = \text{the copper loss at full load}$$

then

$$x + y = 315{,}020 \text{ watts}$$

and

$$x + \frac{y}{16} = 140{,}130 \text{ watts}$$

(the copper loss varies approximately as the square of the load) so that

$$16x + y = 2{,}242{,}080$$

and since

$$\begin{array}{rl} x + y = & 315{,}020 \\ \hline 15x \qquad = & 1{,}927{,}060 \end{array}$$

so that

$$x = 128{,}470 \text{ watts or } 0.71 \text{ per cent}$$

and

$$y = 186{,}550 \text{ watts or } 1.04 \text{ per cent}$$

which check closely with the values as previously read from the chart.

Assuming a voltage to neutral for these transformers of 60,046 volts and a current of 99.92 amp. per conductor, the copper loss of 1.04 per cent will result in an IR voltage drop of $60{,}046 \times 0.0104 = 624$ volts to neutral. The ohms resistance will therefore be $624/99.92 = 6.25$ ohms to neutral for each transformer. Since the resistance of each line conductor is 105 ohms the resistance per conductor including an equivalent value to correspond to the resistance in the high and low tension windings of two transformers will be—

$$R + R_t = 105 + 6.25 + 6.25 = 117.5 \text{ ohms.}$$

TABLE M.—APPROXIMATION OF RESISTANCE AND REACTANCE VOLTS, OF IRON AND COPPER LOSSES AND OF MAGNETIZING CURRENT FOR TRANSFORMERS OF VARIOUS CAPACITIES

Capacity of transformer kv.a.	Per cent resistance*	60 cycles per second				25 cycles per second				
		Per cent reactance*	Per cent loss		Per cent magnetizing current	Per cent resistance	Per cent reactance	Per cent loss		Per cent magnetizing current
			Iron	Copper				Iron	Copper	
200	1.6	5.5	1.1	1.6	10	2.6	4.0	1.1	2.6	10
300	1.4	5.6	1.0	1.4	9	2.2	4.0	1.0	2.2	10
500	1.4	6.0	0.9	1.4	8	1.9	4.1	1.0	1.9	9
750	1.4	6.3	0.7	1.4	7	1.8	4.2	0.9	1.8	9
1,000	1.3	6.5	0.7	1.3	6	1.8	6.0	0.9	1.8	7
1,500	1.2	7.0	0.6	1.2	5	1.8	6.2	0.8	1.8	7
2,000	1.1	7.0	0.6	1.1	5	1.7	6.4	0.7	1.7	6
3,000	1.0	7.0	0.5	1.0	5	1.6	6.8	0.7	1.6	6
5,000	0.8	7.0	0.5	0.8	5	1.4	7.2	0.6	1.4	6
7,500	0.7	8.0	0.5	0.7	4	1.3	7.8	0.6	1.3	6
10,000	0.7	8.0	0.4	0.7	4	1.2	8.0	0.5	1.2	5
15,000	0.6	8.5	0.4	0.6	4	1.1	8.0	0.5	1.1	5
25,000	0.6	9.0	0.4	0.6	4	1.0	8.0	0.5	1.0	5
35,000	0.5	9.5	0.4	0.6	4	0.9	9.0	0.5	0.9	5
50,000	0.5	10.0	0.4	0.5	4	0.8	9.0	0.5	0.8	5

* The actual ohms resistance and ohms reactance will vary as the square of the voltage. The values in above table must be considered as only roughly approximate. They will vary materially with transformers wound for different voltages.

The per cent reactance volts of a transformer having 3.74 per cent regulation at 80 per cent lagging power-factor and 1.04 per cent resistance volts may be read directly from Peter's Regulation Chart by laying a straight edge along the points corresponding to 1.04 per cent resistance and 3.74 on the 80 per cent power-factor line. The intersection of the straight edge with the last solid line at the right will give the per cent reactance = 4.85 per cent.

The per cent reactance volts can also be read directly from the Mershon Chart. To do this, follow upward the vertical line in the Mershon Chart corresponding to 80 per cent power-factor until it intersects the first arc. From this point of intersection follow the horizontal line to the right a distance corresponding to 1.04 per cent resistance volts. From this point thus obtained follow the vertical line until the arc representing 3.74 per cent voltage drops is reached. The length of this vertical line will be the percentage reactance volts of the transformer, in this case 4.8 per cent. Of course the reactance may, if desired, be calculated by following the general construction traced out as above described upon the Mershon Chart, but the chart will give sufficiently accurate values for practical purposes.

The volts necessary to overcome the reactance of the windings of one of these transformers is therefore found to be $60,046 \times 0.048 = 2,882$ volts to neutral. The ohms reactance will therefore be $2,882/99.92 = 28.84$ ohms to neutral for each transformer. Since the reactance of each line conductor is 249 ohms, the reactance per conductor, including an equivalent value to correspond to the reactance in the high and low tension windings of two transformers will be—

$$X + X_t = 249 + 28.84 + 28.84 = 306.68 \text{ ohms.}$$

The impedance of one conductor of the circuit of problem X including the raising and lowering transformers will be—

$$Z = 117.5 + j306.68 \text{ ohms}$$

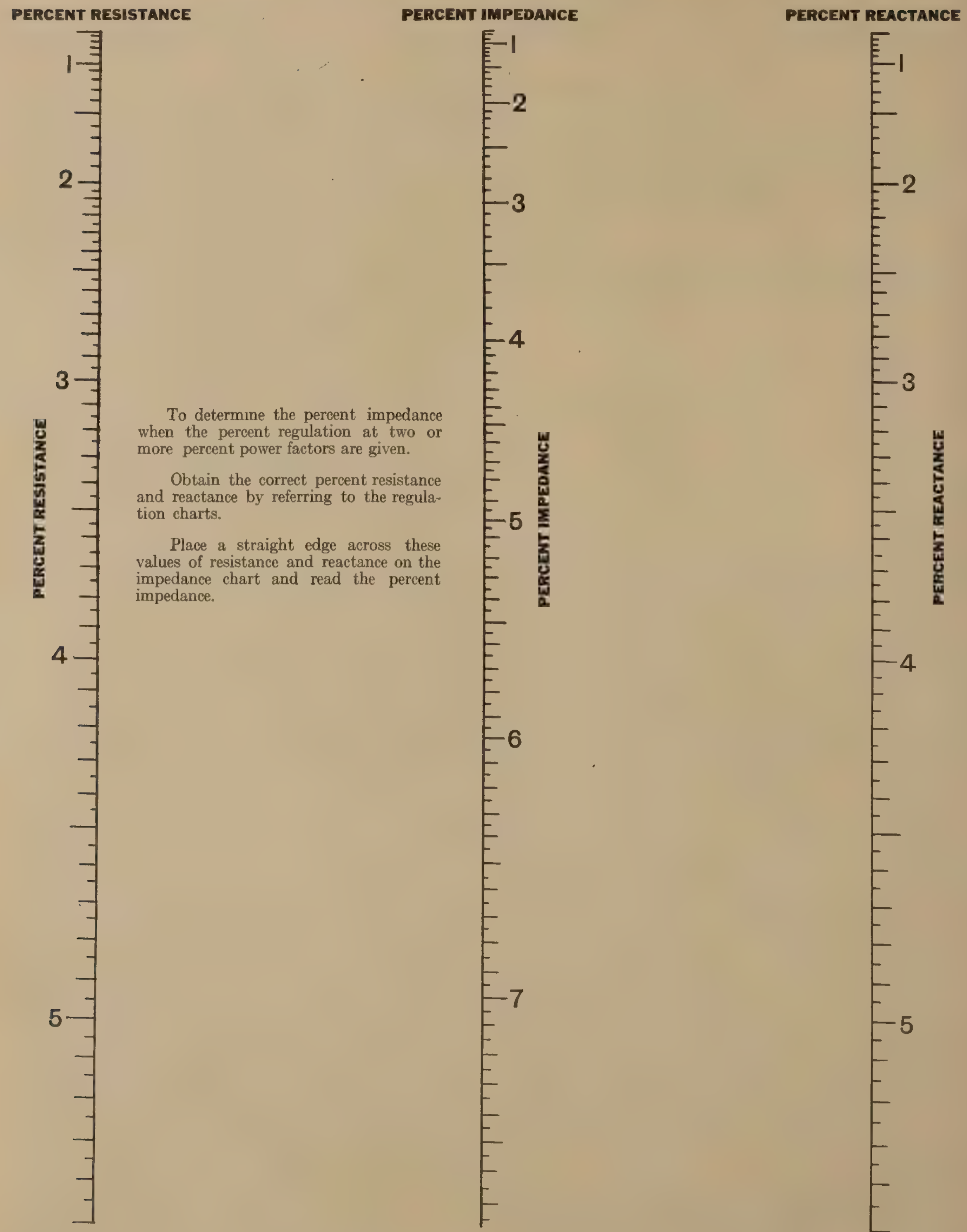
and

Y = (assumed to be the same as without the transformers).

With these new values of impedance (line plus transformers) the performance of the circuit generator to load, may be calculated as though the transformer did not exist. Combining the transformer impedance with that of the line in this way introduces, however, a small error for short lines but an error which increases with the electrical length of the line. In the following chapter a 220 kv. problem is solved by this method as well as by a step-by-step method which accurately accounts for the lumped transformer impedance at the ends of the line. The effect of transformers may also be taken into strict account by the use of general circuit constants as given later.

Usually long transmission circuits have one or more phase modifiers in parallel with the load. Such a transmission circuit must transmit the power loss of the phase modifiers and of the receiver transformers. In addition to this power loss, a lagging reactive current is required to magnetize the transformer iron. A com-

PETERS TRANSFORMER IMPEDANCE CHART



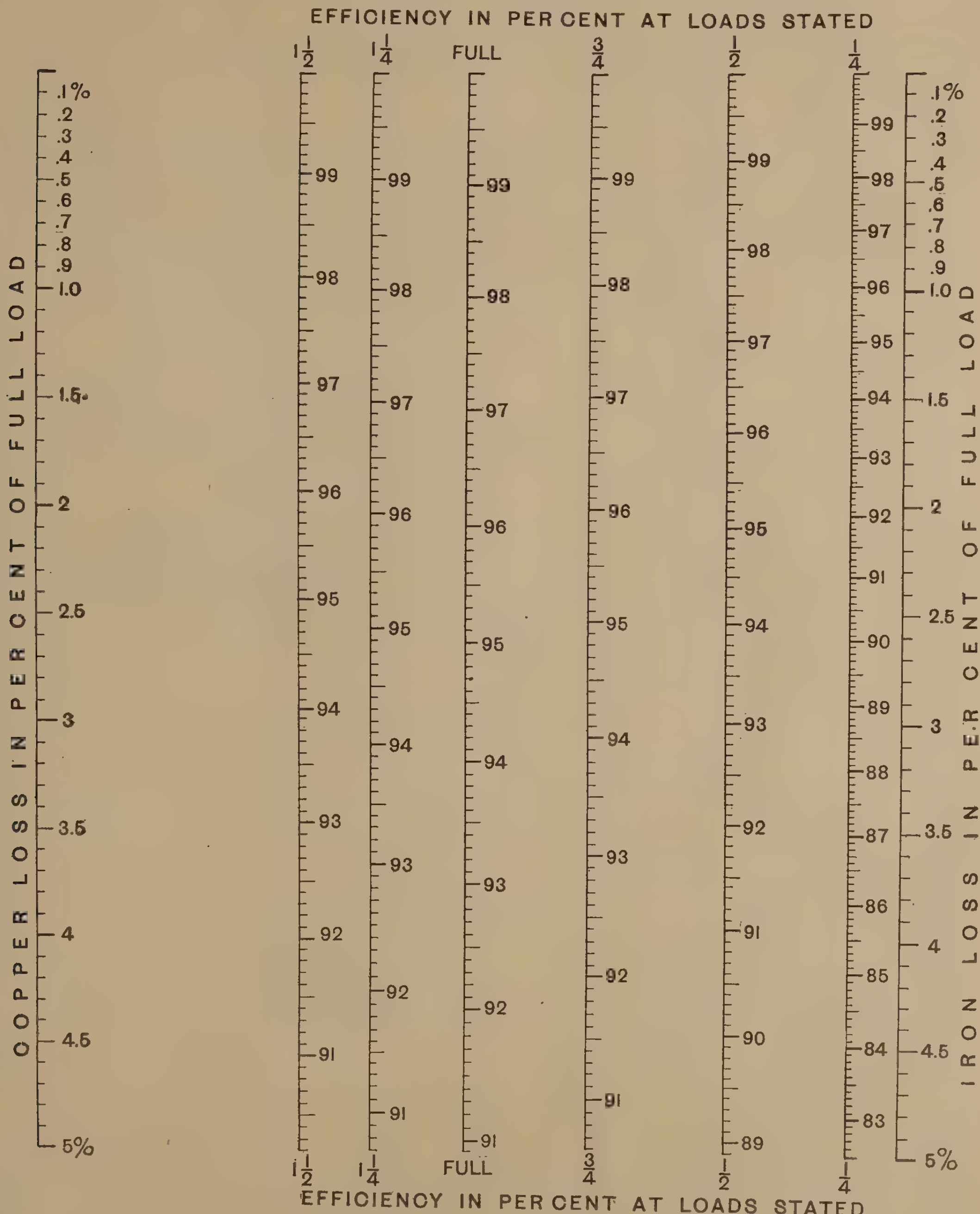
To determine the percent impedance when the percent regulation at two or more percent power factors are given.

Obtain the correct percent resistance and reactance by referring to the regulation charts.

Place a straight edge across these values of resistance and reactance on the impedance chart and read the percent impedance.

PETER'S EFFICIENCY CHART

FOR DETERMINING TRANSFORMER LOSSES AND EFFICIENCIES

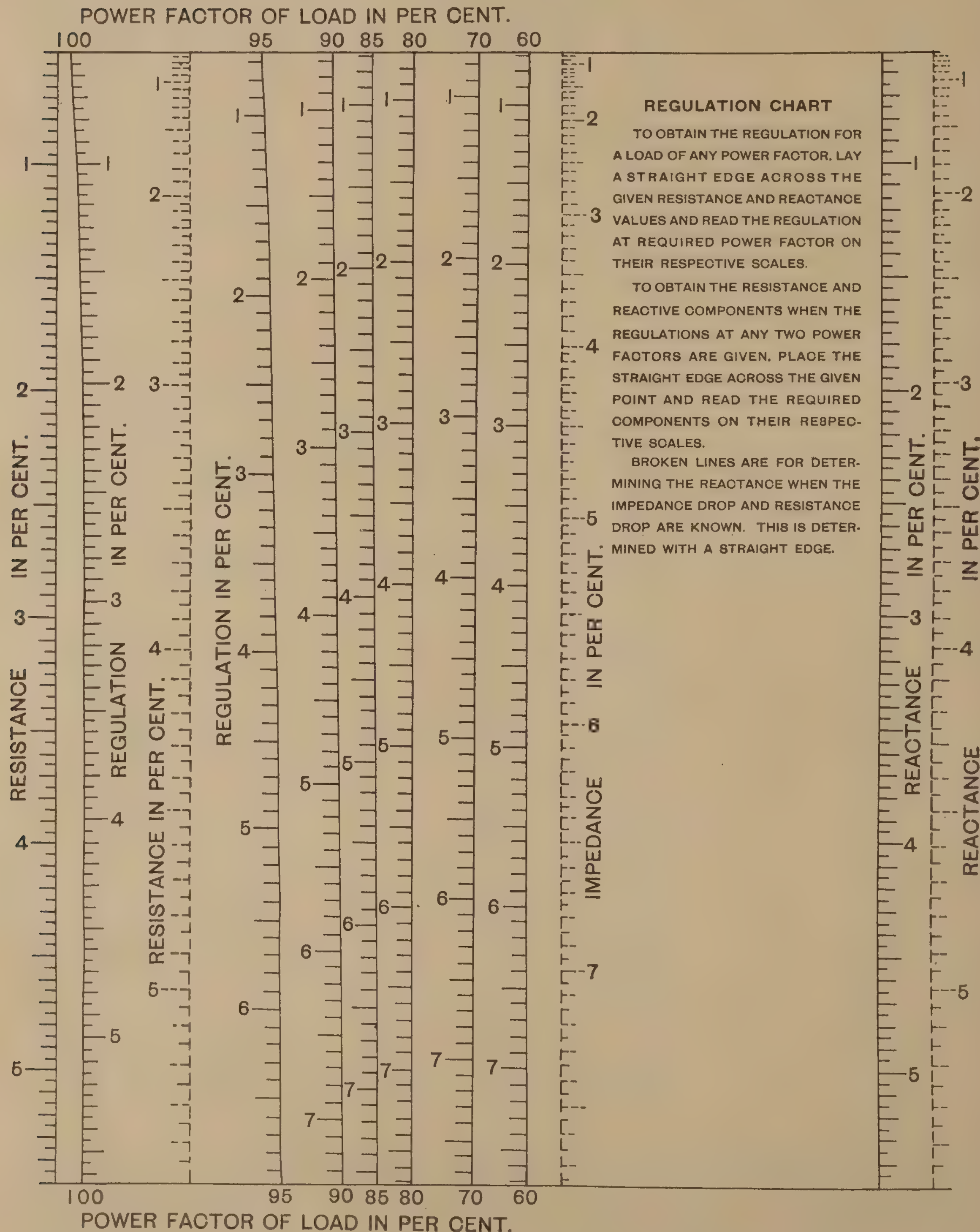


TO OBTAIN EFFICIENCY AT ANY LOAD LAY STRAIGHT EDGE AT GIVEN IRON AND COPPER LOSS POINTS AND READ THE EFFICIENCY AT REQUIRED LOAD ON THEIR RESPECTIVE SCALES WHERE STRAIGHT EDGE CROSSES THEM.

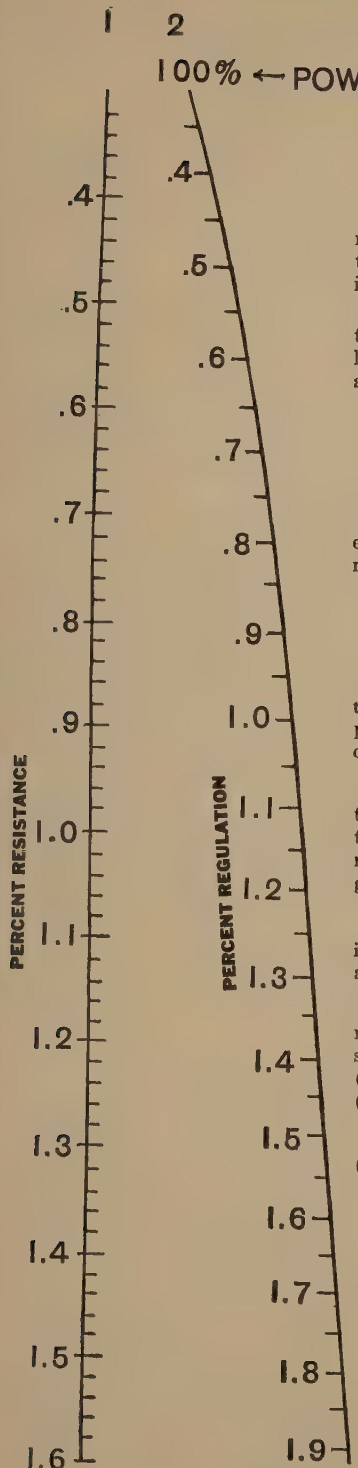
VICE VERSA, TO OBTAIN LOSSES, PLACE STRAIGHT EDGE ACROSS ANY TWO GIVEN EFFICIENCY POINTS AND READ PER CENT IRON AND COPPER LOSS ON THEIR RESPECTIVE SCALES.

PETER'S REGULATION CHART

FOR DETERMING DISTRIBUTION TRANSFORMER REGULATION



PETERS POWER TRANSFORMER REGULATION CHART



1. Method of determining the percent reactance drop in the transformer when the per cent resistance and the per cent impedance drops are known.

The per cent resistance drop (R) in a transformer may be found from the full load copper loss given in the performance specifications as follows:

Per cent resistance drop=

$$\frac{\text{Watts Copper Loss}}{10 \text{ (KVA Transformer)}}$$

The per cent impedance drop (Z) of each transformer is stamped on the name plate.

The per cent reactance drop

$$(X)=\sqrt{Z^2-R^2}.$$

2. Method of determining the regulation at different power factors when the per cent resistance and per cent reactance drops are known.

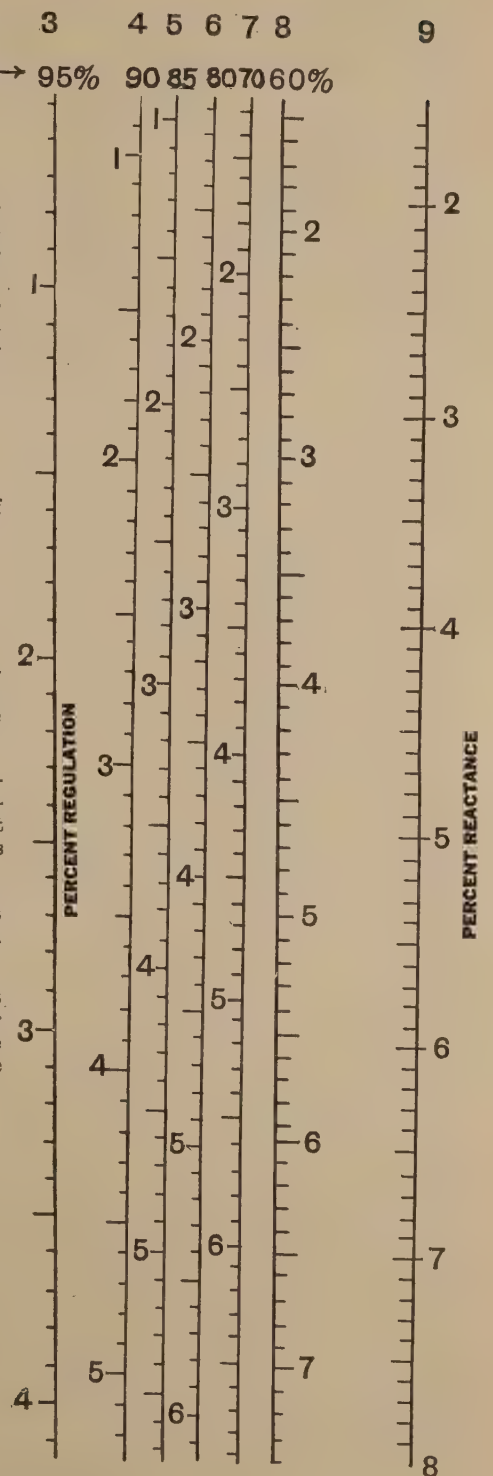
Place straight edge at per cent resistance, scale one, and at percent reactance, scale nine. Read the per cent regulation at different power factors as given by 2 to 8 inclusive.

3. Method of determining per cent impedance given the per cent regulation at 2 or more per cent power factors.

Place straight edge at the per cent regulations on the correct power factor scales and read the per cent resistance (R) on scale one and per cent reactance (X) on scale nine.

The per cent impedance

$$(Z)=\sqrt{R^2+X^2}.$$



plete solution of such a composite circuit (generator to load) requires that the losses of the phase modifiers and transformers be added vectorially to the load at the point where they occur so that their complete effect may be included in the calculation of the performance of the circuit. A complete solution also requires that three separate solutions be made for such a circuit. First with the known or assumed conditions at the load side of the lowering transformers the corresponding electrical conditions at the high voltage side of the transformers is determined by the usual short line impedance methods. With the electrical conditions at the receiving end of the high-tension line thus determined, the electrical conditions at the sending end of the line are determined by one of the various methods which take into account the distributed quantities of the circuit. With the electrical condition at the sending end thus determined the electrical conditions at the generating side of the raising transformers are determined. The above complete method of procedure, is tedious if carried out mathematically, but if carried out graphically is comparatively simple.

It is the general practice to neglect the effect of condenser and lowering transformer loss in traveling over the line, but to add this loss to the loss in the high-tension line after the performance has been calculated. If the loss in condensers and lowering transformers is five per cent of the power transmitted the error in the calculated results would probably be less than 0.5 per cent, a rather small amount.

In order to simplify calculations, it is the general practice to consider the lumped transformer impedance as though it were distributed line impedance by adding it to the linear constants of the line and then proceeding with the calculations as though there were no transformers in the circuit. This simplifies the solution but at the expense of accuracy, particularly, if the line is very long, the frequency high or the ratio of transformer to line impedance high. This simplified solution introduces maximum errors of less than two per cent in the results for a 225 mile, 60-cycle line.

It has been quite general practice to disregard the effect of the magnetizing current consumed by transformers. The magnetizing current required to excite transformers containing the older transformer iron was about two per cent and therefore its effect could generally be ignored. Later designs of transformers employ silicon steel, and their exciting current varies from about 20 per cent for the smaller of distribution type transformers, to about 10 per cent on transformers of 100 kv.a. capacity and about 5 per cent for the very largest capacity transformers as indicated in Table M. The average magnetizing current for power transformers is between 6 and 8 per cent. This magnetizing current is important for the reason that it is practically in opposition to the current of over-excited phase modifiers used to vary the power-factor. If in a line having 100,000 kv.a. transformer capacity at the receiving end, the magnetizing current is 5 per cent, there will be a 5,000 kv.a. lagging component. If the capacity of phase modifiers required to maintain the proper voltage drop under this load is 50,000 kv.a. the lagging magnetizing component of 5,000 kv.a. will subtract this amount from the effective rating of the phase modifiers, with a resulting error of 10 per cent in the capacity of the phase modifiers required.

In the diagrams and calculations which follow, the transformer leakage, consisting of an in-phase component of current (iron loss) and a reactive lagging component of current (magnetizing current), is considered as taking place at the low-tension side of the transformers. A more nearly correct location would be to consider the leak as at the middle of the transformer, that is, to place half the transformer impedance on each side of the leak. To solve such a solution it would be necessary to solve two complete impedance diagrams for the transformers at each end of the circuit. The gain in accuracy of results would not, for power transmission lines, warrant the increased arithmetical work and complication necessary.

In the case of lowering transformers, it would seem that the magnetizing current would be supplied principally from synchronous machines connected to the load. If phase modifiers are located near the lowering transformers, the transformers would probably draw most of their magnetizing current from them rather than from the generators at the distant end of the line. Partly for this reason, but more particularly for simplicity, the leak of the lowering transformers will be considered as taking place at the load side of the transformers. On this basis we first have a load current expressed in rectangular coordinates with the load voltage as a temporary vector of reference. To this we add algebraically a phase modifier current (loss $+ j$ or leading) and to this we add the transformer leakage (loss $- j$ or lagging). In other words, these three components of current at the receiving end of the line add up algebraically upon a common vector of reference, thus making it very easy to obtain the resulting load at the receiving end of the line.

The transformers at the sending end of the line have been considered as receiving their magnetizing current also from the low side; that is from the generators. Both the complete and the approximate methods of solving long line problems which follow, include the effect of not only the magnetizing current consumed by the transformers, but also the losses in transformers and phase modifiers flowing over the line.

For the purpose of determining the magnitude of errors in the calculated results corresponding to simplified methods of calculation where transformers are required at both ends of the line, the calculations shown in Table N were made. Five methods of calculations were made for each of four sizes of cable. A constant load, load voltage and condenser capacity were assumed for all calculations and the results of these calculations are tabulated in Table N. Thus method B which does not take any account of the lowering transformer magnetizing current and assumes the transformer impedance as line impedance, gives the sending end

TABLE N.—COMPARISON OF RESULTS AS OBTAINED BY FIVE DIFFERENT METHODS OF CALCULATIONS

75,000 kw. (88,235 kv.a. at 85 per cent PF) 3 phase, 60 cycles, receiver voltage held constant at 220 kv., 50,000 kv.a. condenser at receiving end, length of transmission 225 miles. All tabulated values referred to neutral

Area in circular mils	*Method	Receiving end to neutral						Sending end to neutral										Losses in kw. to neutral								
		Low tension side of transformers			High tension side of transformers			High tension side of transformers					Low tension side of transformers					Lowering transformers		Condenser	High tension line		Raising transformers		Total loss	
								Voltage		Current			Voltage		Current											
		Volts E_{ln}	Amp. $I_l + I_c$	PF_l lead	Volts E_{rn}	Amp. I_r	PF_r lag	E_{sn}	Per cent	I_s	Per cent	PF_s lead	E_{gen-n}	Per cent	I_{gen}	Per cent	PF_{gen} lead	Iron	Copper		KW_n	Loss in per cent of KW_n	Iron	Copper	KW_n	Loss in per cent of KW_n
605,000	A	127,020	202.3	99.90	127,556	204.9	99.63	129,090	100	227.8	100	93.77	126,920	100	226.1	100	97.49	235	130	666	1,542	6.16	235	165	2,973	11.89
605,000	B	127,020	202.3	99.90	....	.....	.....	124,247	96.3	236.5	103.9	93.35	....	.....	.....	.....	.....	235	130	666	1,634	6.53	235	178	3,078	12.31
605,000	C	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	124,657	98.2	232.3	102.8	95.14	235	130	666	1,583	6.33	235	172	3,021	12.08
605,000	D	127,020	202.3	99.90	....	.....	.....	126,783	98.4	228.7	100.4	94.32	....	.....	.....	.....	.....	235	130	666	1,553	6.21	235	166	2,985	11.94
605,000	E	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	127,537	100.5	224.6	99.3	95.87	235	130	666	1,510	6.04	235	160	2,936	11.74
715,500	A	127,020	202.3	99.90	127,556	204.9	99.63	127,911	100	228.7	100	93.50	125,668	100	226.6	100	97.36	235	130	666	1,320	5.28	235	166	2,752	11.01
715,500	B	127,020	202.3	99.90	....	.....	.....	123,041	96.2	237.5	103.9	93.09	....	.....	.....	.....	.....	235	130	666	1,408	5.63	235	180	2,854	11.42
715,500	C	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	123,409	98.2	223.1	102.8	94.93	235	130	666	1,338	5.35	235	173	2,777	11.11
715,500	D	127,020	202.3	99.90	....	.....	.....	125,576	98.2	229.7	100.4	94.09	....	.....	.....	.....	.....	235	130	666	1,349	5.40	235	168	2,783	11.13
715,500	E	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	126,292	100.5	225.4	99.5	95.67	235	130	666	1,273	5.09	235	162	2,701	10.80
795,000	A	127,020	202.3	99.90	127,556	204.9	99.63	127,196	100	229.3	100	93.33	124,909	100	227.4	100	97.24	235	130	666	1,192	4.77	235	167	2,625	10.50
795,000	B	127,020	202.3	99.90	....	.....	.....	122,313	96.2	238.0	103.8	92.94	....	.....	.....	.....	.....	235	130	666	1,260	5.04	235	181	2,707	10.83
795,000	C	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	122,648	98.2	233.5	102.7	94.80	235	130	666	1,177	4.71	235	174	2,617	10.47
795,000	D	127,020	202.3	99.90	....	.....	.....	124,846	98.1	230.2	100.4	93.94	....	.....	.....	.....	.....	235	130	666	1,198	4.79	235	169	2,633	10.53
795,000	E	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	125,532	100.5	225.8	99.3	95.55	235	130	666	1,126	4.50	235	162	2,554	10.22
954,000	A	127,020	202.3	99.90	127,556	204.9	99.63	126,132	100	230.4	100	92.93	123,740	100	228.4	100	96.99	235	130	666	976	3.90	235	169	2,411	9.64
954,000	B	127,020	202.3	99.90	....	.....	.....	121,212	96.1	239.4	103.9	92.55	....	.....	.....	.....	.....	235	130	666	1,059	4.23	235	183	2,508	10.03
954,000	C	127,020	202.3	90.90	....	.....	.....	....	.....	.....	.....	.....	121,488	98.2	235.1	102.9	94.51	235	130	666	1,020	4.08	235	177	24.63	9.85
954,000	D	127,020	202.3	99.90	....	.....	.....	123,737	98.1	231.5	100.5	93.58	....	.....	.....	.....	.....	235	130	666	1,014	4.05	235	170	2,450	9.80
954,000	E	127,020	202.3	99.90	....	.....	.....	....	.....	.....	.....	.....	124,368	100.5	227.3	99.5	95.31	236	130	666	984	3.93	235	165	2,415	9.66

* A—Transformer impedances treated as lumped at the ends of the line This is the most nearly accurate of the five methods. It is referred to in the text as the complete solution.

B—This assumes the impedance of the lowering transformers as line impedance. It takes no account of the leakage of the lowering transformers.

C—This assumes the impedance of both lowering and raising transformers as line impedance—it takes no account of the leakage of the lowering and raising transformers.

D—This is the same as B except that the leakage of the lowering transformers has been added to the load—it is referred to in the text as the approximate solution

E—This is the same as C except that the leakage of the lowering transformers has been added to the load.

TABLE O.—PERCENTAGE ERRORS IN RESULTS, AS DETERMINED BY VARIOUS METHODS OF CALCULATION

These methods do not take complete account of the effects of the transformers in the circuit

Method	At generator per cent error			At sending end per cent error			Line loss per cent error	Transformer account
	E_{gen}	I_{gen}	PF_{gen}	E_s	I_s	PF_s		
A	0	0	0	0	0	0	0	Complete method—assumed for comparison as resulting in 100 per cent values.
B	.....	.....	......	−3.7	+3.9	−0.42	+0.37	Leak of lowering transformers ignored. Impedance of lowering transformers assumed as line impedance.
C	−1.8	+2.8	−2.35	.....	.....	......	+0.17	Leaks of raising and lowering transformers ignored. Impedance of raising and lowering transformer assumed as line impedance.
D	.....	.....	......	−1.6	+0.4	+0.55	+0.05	Same as B except that the transformer leak has been added to the load.
E	+0.5	−0.7	−1.62	.....	......	......	−0.12	Same as C except that the transformer leak has been added to the load.

voltage too low by 3.7 per cent and the current too high by 3.9 per cent.

Figure 67 shows complete current and voltage diagrams for both short and long lines. The diagram illustrating short lines is based upon the current having the same value and direction at all points of the circuit. On this basis the IR drops of the line and of the raising and lowering transformers will be in the same direction. Likewise their individual IX drops will also be in the same direction. It is evident, therefore, that, for short lines where the capacitance is negligible, the transformer impedance may be added directly to the line impedance, provided the electrical characteristics on the high-tension side of the transformers are not required.

As the line becomes longer, the current changes in both amount and direction from point to point, as a result of the superimposed distributed charging current of the line. The result of this is that the impedance triangles of the line and of lowering and raising transformers change in both size and relative position; so that their individual impedances can no longer be added together and considered as all line impedance, without accepting an error in the results thus obtained. The complete diagram for long lines shown by Fig. 67 will be considered later.

TRANSFORMER IMPEDANCE TO NEUTRAL*

Transformer constants are referred to the high voltage circuit in order to combine properly with the linear constants of the line. Although all calculations are made in terms of the high-voltage circuit the results may, if desired, be converted to terms of the low voltage circuit, by applying the ratio of transformation.

The transformer impedance to neutral is one-third the equivalent single-phase value. The reason for this is that the I^2R and I^2X for one phase is identical whether to neutral or between phases. Since the current between phases is equal to the current to neutral divided by $\sqrt{3}$, the square of the phase current would be one-third the square of the current to neutral; therefore, R and X to neutral will be one-third the phase values. Another way of looking at this is that the resistance and reactance ohms vary with the square of the voltage, and since the phase voltage is $\sqrt{3}$ times the voltage to neutral, the phase resistance and phase reactance would be three times that to neutral. In calculating the impedance to neutral, the results will be the same whether star or delta connection is used.

Even if the transformers at both ends of the transmission line are duplicates their impedance will not be the same if operated on different taps of the windings to accommodate different voltages. In such cases, their impedances will vary as the square of the voltages. For instance, if they are operated at 220 and 230 kv. at the receiving and sending end respectively, then their impedances will have the relation of $220^2/230^2 = 0.915$. In other words, if the resistance and reactance of the receiving end transformers is 3.185 and 39.82 ohms respectively, the sending end transformers will have resistances and reactances of 3.481 and 43.52 ohms respectively; provided transformer taps corresponding to this higher voltage are used.

The impedance in ohms of an 18,000 kv.a., three-phase, or of three 6,000 kv.a. single-phase transformers, connected in a bank, may be determined as follows. Assume that they are operated at 104,000 volts between conductors (60,046 to neutral) and that the resistance voltage is 1.04 per cent and reactance voltage is 4.80 per cent.

The single-phase values are:

$$\frac{6{,}000{,}000}{104{,}000} = 57.7 \text{ amp.}$$

$$R_t = \frac{104{,}000 \times 0.0104}{57.7} = 18.75 \text{ ohms resistance}$$

$$X_t = \frac{104{,}000 \times 0.048}{57.7} = 86.52 \text{ ohms reactance}$$

The values to neutral are, as stated above, one-third of the above; but, for the sake of uniformity in determining values to neutral, should preferably be determined as follows:

$$\frac{6{,}000{,}000}{60{,}040} = 99.92 \text{ amp. to neutral}$$

$$R_{tn} = \frac{60{,}046 \times 0.0104}{99.92} = 6.25 \text{ ohms resistance to neutral}$$

$$X_{tn} = \frac{60{,}046 \times 0.0480}{99.92} = 28.84 \text{ ohms reactance to neutral}$$

If two or more banks operate in parallel, the resulting impedance Z_r can be obtained by taking the reciprocal of the sum of the reciprocals of the individual impedance. Thus:

$$Z_r = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

In the above example $Z_t = \sqrt{1.04^2 + 4.8^2} = 4.91$ per cent.

To parallel two banks containing transformers duplicates of the above, we get, by the above rule, the following resultant impedance:

$$Z_r = \frac{4.91 \times 4.91}{4.91 + 4.91} = 2.45 \text{ per cent}$$

Which is just half the impedance of a single bank, as is evident without applying the rule.

Where two or more banks are to be operated in parallel consisting of transformers not duplicates, then the above rule must be applied to determine the resultant impedance. If the impedances are expressed in per cent, as is usual, then they must be both referred to the same kv.a. base. For instance, if a 6,000 kv.a. and a 3,000 kv.a. transformer each have a resistance of 1.04 per cent and a reactance of 4.8 per cent, their impedance is 4.91 per cent. Before combining the impedances, that of the 3,000 kv.a. unit should be put in terms of the 6,000 kv.a., and the resultant would be:

$$Z_r = \frac{4.91 \times 9.82}{4.91 + 9.82} = 3.27 \text{ per cent at 6,000 kv.a.}$$

$$= 0.69 \text{ per cent resistance volts at 6,000 kv.a.}$$

$$= 3.19 \text{ per cent reactance volts at 6,000 kv.a.}$$

* The writer desires to express his appreciation of helpful assistance and useful data on transformer characteristics received from Mr. J. F. Peters.

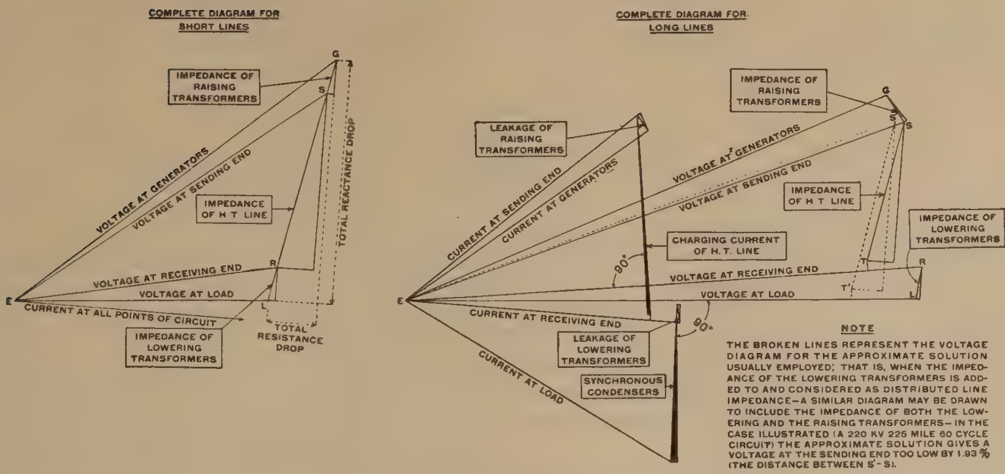


FIG. 67.—Vector diagrams for short and long lines.

If the impedance triangles of the two banks to be paralleled are considerably different (that is their ratio of resistance to reactance) it will be necessary to express the impedances in complex form. We have assumed above that the triangles are proportional, otherwise they would not divide the load evenly at all power-factors. Solving the preceding problem for the resultant impedance by complex notation, we get:

$$Z_r = \frac{(1.04 + j4.8) \times (2.08 + j9.6)}{(1.04 + j4.8) + (2.08 + j9.6)}$$

$$= \frac{-43.917 + j19.968}{3.12 + j14.4}$$

$$= \frac{48.25\underline{/155^\circ\ 32'\ 58''}}{14.734\underline{/77^\circ\ 46'\ 29''}}$$

$$= 3.27\underline{/77^\circ\ 46'\ 29''} \text{ ohms}$$

$$= 0.69 + j3.19 \text{ ohms}$$

Which checks with the results determined above on the percentage basis.

In case of 3-winding transformers the reactance between high and low voltage windings changes with the load taken off of the third winding. This third winding usually feeds a phase modifier which has its load continually varied in order to hold the voltage constant. It is general practice to assume a single transformer impedance sufficiently high and to then disregard the effect of the third winding upon the transformer impedance. For information on 3-winding transformers the reader is referred to articles in the Electric Journal of February 1925, by J. F. Peters.

CHAPTER XIV

A TYPICAL 220-KV. PROBLEM

To illustrate the method of determining the performance of long lines requiring phase modifiers for voltage control, the following 220-kv. problem will be considered, which is typical of many likely to be considered in the near future. A line necessitating such large expenditure would warrant a thorough investigation before determining the final design. The conclusions are given only for the purpose of illustrating the procedure.

The Problem.—It is assumed that 300,000 kw. at 85 per cent lagging power-factor is to be delivered a distance of 225 miles, at 220 kv. three-phase, 60 cycles. Two lines will be required, so that in case one is under repair, the other will transmit the entire 300,000 kw. load. Since the self-induced voltage would be excessive if the 300,000 kw. were transmitted in emergency over a single-circuit tower line, we will assume that each tower line will support two three-phase circuits. The cost of two three-phase circuits per tower line will not be greatly in excess of a single circuit tower line employing conductors of double the cross-section. On this basis each of the four three-phase circuits will normally transmit 75,000 kw. and, under emergency condition, each of the two circuits on one tower line will transmit 150,000 kw. Such a transmission is illustrated by Fig. 69.

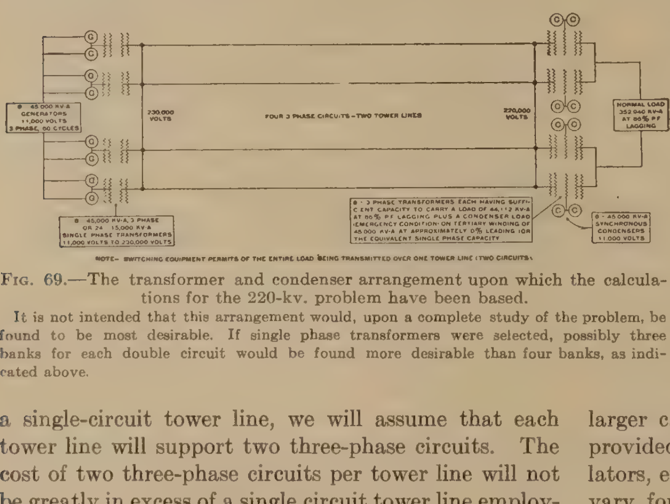


FIG. 69.—The transformer and condenser arrangement upon which the calculations for the 220-kv. problem have been based.

It is not intended that this arrangement would, upon a complete study of the problem, be found to be most desirable. If single phase transformers were selected, possibly three banks for each double circuit would be found more desirable than four banks, as indicated above.

Economic Size of Conductors.—For a fixed transmission voltage and material of conductors, the most economic size of conductor will be found by applying Kelvin's Law extended to include, in addition to the cost of conductors, that part of the cost of towers, insulators, line construction, phase modifiers, etc. which increases with the cost of conductors. Kelvin's law is as follows:

"The most economical section of a conductor is that which makes the annual cost of the I^2R losses equal to the annual interest on the capital cost of the conducting material plus the necessary annual allowance for depreciation." Stated another way, "The annual cost of the energy wasted, added to the annual allowance for depreciation and interest on first cost shall be a minimum."

In Table *Y* is shown a comparison of values of capitalized losses *vs.* first costs of conductors for four sizes of aluminum-steel cables considered in connection with this 220-kw. problem.* The cost of power losses is based upon rates of 0.3, 0.4 and 0.5 ct. per kw. hour, an average load corresponding to 80 per cent of the full load loss and a capitalization of these losses at 15 per cent. The cost of the cables is based upon 29 cts. per pound for the complete cable (aluminum plus the steel). All tabulated data is based upon four three-phase circuits. The losses include those in the high voltage line only. If the capacity of transformers or phase modifiers varies materially for different conductors, the difference in their losses should be included.

If the base load power generated in such a large amount by water power costs 0.3 ct. per kw.-hr., the values in Table *Y* show that the smallest size cable, 605,000 circ. mils will be the cheapest to install. At 0.3 ct. per kw.-hr. the power loss for this cable, capitalized at 15 per cent, represents the equivalent of an investment of $2,593,000 for the four three-phase circuits, whereas the cost of the conductors is $3,224,000. If the cost of power loss is taken as 0.4 ct. per kw.-hr., the next larger cable will be the most economical size to use, provided that there is no increased cost of towers, insulators, etc. If the losses in transformers or condensers vary for the different sizes of cables compared such losses should be included with the conductor losses.

There is always a question as to what price should be charged in Kelvin's equation in estimating the cost of power loss. If all power saved could be promptly sold, the cost to allow might be considered the cost at the consumers meter. If, on the contrary, none of the power saved can be sold under any circumstances, then the cost to allow is the cost at the generating switchboard. Intermediate cases may occur.

The conductor losses of Table *Y* were taken from the calculated values by the complete method *A* listed in Table *N*.† It is usually sufficient to calculate the loss in the conductors for one size of cable and to esti-

*An interesting graphic presentation of Kelvin's Law is given in the article by Mr. L. J. MOORE: *Electrical World*, Sept. 24, 1921, p. 612.

† Chapter XIII.

mate it for other sizes of cable, assuming that this loss varies as the resistance of the conductors, that is, for a given line, frequency, load, delivery voltage and con-

TABLE Y.—APPLICATION OF KELVIN'S LAW

Conductors circ. mils	Total loss in 12 conductors kw.	Cost of power lost in 12 conductors, capitalized at 15 per cent			Cost of 12 conductors at 29 ct. per lb.
		At 0.3 ct. per kw.-hr.	At 0.4 ct. per kw.-hr.	At 0.5 ct. per kw.-hr.	
*605,000	18,504	$2,593,000	$3,458,000	$4,322,000	$3,224,000
715,500	15,840	$2,220,000	$2,960,000	$3,700,000	$3,837,000
795,000	14,304	$2,040,000	$2,673,000	$3,341,000	$4,244,000
954,000	11,712	$1,641,000	$2,188,000	$2,736,000	$5,011,000

* This is the smallest conductor which is, in this case, permissible on account of corona limitations. These tabulations are total for four three-phase circuits. It will usually be sufficiently accurate to calculate the conductor I^2R loss for one size of conductor and assume that the loss for other sizes will be proportional to their resistances. This assumes that the distribution of current throughout the length of circuit will be approximately the same for the different sizes of conductors compared. The above data is based upon 75,000 kw. at 85 per cent power-factor, three-phase, 60 cycles, delivered over each of the four circuits a distance of 225 miles at 220 kv. with a 50,000 kv.a. condenser in parallel with the load on each of the four circuits and an average load equivalent to 80 per cent of full load. It should be noted that the third, fourth and fifth columns do not give the actual cost of the power lost, but give instead the values at which these losses are capitalized.

denser capacity the current distribution in the line is approximately the same for various sizes of conductors likely to be considered. Since the conductor loss varies as the square of the current and directly as the resistance, it will be sufficient to estimate the loss for other conductors as being directly proportional to their resistance.

The various constants corresponding to the four sizes of conductors considered are listed in Table Z. It may be interesting to note the variation in these constants corresponding to the different sizes of cable for the high-tension line alone, and also when the transformer impedances are included with the line impedance.

SOLUTION OF THE 220-KV. PROBLEM

Assuming that 605,000 circ. mil aluminum-steel cables work out as the most economical size, the next step is the determination of the auxiliary constants A, B, and C for this size of conductor, spacing and 60 cycles. (These constants would have previously been determined when determining the most economical size.) Mathematically these constants may be calculated by real hyperbolic functions (Chart XVI) or by convergent series (Chart XI). Graphically, they may be obtained from Wilkinson's Charts (Charts V, VI and VII) or through the medium of Dr. Kennelly's Charts (Charts XVIII, XIX, XX and XXI). When using charts it is desirable to read the results from them at two different times as a check against errors in reading, or the constants may be read from both the Wilkinson and Kennelly Charts and the results compared. From old table we find $r = 0.154$ ohm, so that $R = 0.154 \times 225 = 34.65$ ohms and $x = 0.792$ so that $X = 0.792 \times 225 = 178.2$ ohms. From old table we obtain $b = 5.38 \times 10^{-6}$ so that $B = 5.38 \times 225 \times 10^{-6} = 0.001211$ mho. G is assumed here as zero.

From Wilkinson Charts.

$$a_1 = 0.892$$

$$\text{and since } rb = 0.828$$

$$a_2 = 0.020$$

$$b_1 = 32.2 \text{ ohms}$$

$$b_2 = 173.5 \text{ ohms}$$

$$\text{and since } rb^2 = 4.457$$

$$c_1 = \text{(too small to read)}$$

$$c_2 = 0.001175$$

From Dr. Kennelly's Charts.—We must first obtain the hyperbolic complex angle of the circuit as follows:

$$\begin{aligned} Z &= 34.65 + j178.2 \\ &= 181.54\,\underline{|78^\circ\ 59'\ 46''} \\ Y &= 0 + j0.001211 \\ &= 0.001211\,\underline{|90^\circ} \\ ZY &= 0.21984\,\underline{\diagdown 168^\circ 59' 46''} \\ \theta = \sqrt{ZY} &= 0.4689\,\underline{|84^\circ 29' 53''} \end{aligned}$$

$$\text{From Chart XIX, } \frac{\sinh \theta}{\theta} = 0.964\,\underline{/0.4^\circ}$$

$$= 0.964\,\underline{/0^\circ 24' 0''}$$

$$\text{From Chart XXI, } \frac{\tanh \theta}{\theta} = 1.0785\,\underline{\diagdown 0.88^\circ}$$

$$= 1.0785\,\underline{\diagdown 0^\circ\ 52'\ 48'}$$

TABLE Z.—CABLE AND CIRCUIT CONSTANTS CORRESPONDING TO A THREE-PHASE, 60-CYCLE CIRCUIT, 225 MILES LONG, CONSISTING OF FOUR SIZES OF ALUMINUM CABLES OF AN ARRANGEMENT EQUIVALENT TO 21 FT. DELTA

AREA OF CONDUCTORS (C M)				DIA. OF ALUM COND.	STRANDS		LINEAR CONSTANTS OF LINE TO NEUTRAL								IMPEDANCE TO NEUTRAL OF 50,000 KV A BANK OF TRANSFORMERS *			
ALUM.	STEEL	TOTAL	COPPER EQUIV		AL.	ST	r	x	g	b ×10⁻⁶	R	X	G	B ×10⁻⁶	R_{TN}	X_{TN}	G_{TN}	B_{TN} ×10⁻⁶
605,000	78,000	683,500	380,400 EQUIV	0.952	54	7	0.154	0.792	0	5.38	34.65	178.2	0	1211	6.37	79.64	0	0
715,500	92,900	808,900	450,000 EQUIV	1.036	54	7	0.131	0.782	0	5.45	29.48	175.9	0	1226	6.37	79.64	0	0
795,000	103,100	898,100	500,000 EQUIV	1.092	54	7	0.117	0.775	0	5.49	26.33	174.4	0	1235	6.37	79.64	0	0
954,000	123,700	1,077,700	600,000 EQUIV	1.196	54	7	0.0978	0.764	0	5.58	22.00	171.9	0	1256	6.37	79.64	0	0

	LINEAR CONSTANTS				HYPERBOLIC QUANTITIES		AUXILIARY CONSTANTS OF CIRCUIT		
	R	X	G	B ×10⁻⁶	θ = √ZY	Z₀ = √(Z/Y)	(A)	(B)	(C)
HIGH TENSION LINE (TO NEUTRAL)									
605,000	34.65	178.2	0	1211	.04496 + j.466738 = .4689 /84°29′53″	387.2 \5°30′07″	.893955 + j.020234 = .89418 /1°17′47″	32.198 + j 172.094 = 175.1 /79°24′10″	−.000 008 + j.001168 = .001168 \90°24′24″
715,500	29.48	175.9	0	1226	.03879 + j.46599 = .4676 /85°14′29″	381.4 \4°45′25″	.894044 + j.017429 = .8942 /1°07′01″	27.394 + j 169.818 = 172.01 /80°50′11″	−.000 007 + j.001182 = .001182 \90°21′01″
795,000	26.33	174.4	0	1235	.034933 + j.46538 = .4667 /85°42′26″	377.9 \4°17′33″	.894183 + j.015681 = .8944 /1°0′16″	24.47 + j 168.344 = 170.11 /81°43′47″	−.000 006 + j.001191 = .001191 \90°18′54″
954,000	22.00	171.9	0	1256	.029684 + j.46576 = .4667 /86°21′12″	371.6 \3°38′47″	.893944 + j.013326 = .89404 /0°51′14″	20.44 + j 165.88 = 167.1 /82°58′29″	−.000 006 + j.001211 = .001211 \90°16′04″
HIGH TENSION LINE PLUS IMPEDANCE OF LOWERING TRANSFORMERS (TO NEUTRAL)									
605,000	37.83	218.02	0	1211	.044417 + j.515789 = .5177 /85°04′41″	427.47 \4°55′18″	.870783 + j.021911 = .87106 /1°26′29″	34.5653 + j 208.83 = 211.67 /80°36′06″	−.000 009 + j.001158 = .001158 \90°26′43″
715,500	32.66	215.72	0	1226	.03882 + j.515741 = .5172 /85°41′43″	421.85 \4°18′16″	.870587 + j.019150 = .87079 /1°15′36″	29.837 + j 206.545 = 208.69 /81°46′49″	−.000 007 + j.001173 = .001173 \90°23′22″
795,000	29.51	214.22	0	1235	.035347 + j.51559 = .5168 /86°04′41″	418.44 \3°55′18″	.870556 + j.017429 = .87073 /1°08′49″	26.9585 + j 205.0706 = 206.83 /82°30′39″	−.000 007 + j.001181 = .001181 \90°21′15″
954,000	25.18	211.72	0	1256	.030613 + j.51658 = .5175 /86°36′31″	412.01 \3°23′28″	.869919 + j.015121 = .87005 /0°59′45″	22.992 + j 202.588 = 203.89 /83°31′30″	−.000 006 + j.001201 = .001201 \90°18′27″
HIGH TENSION LINE PLUS IMPEDANCE OF BOTH LOWERING AND RAISING TRANSFORMERS (TO NEUTRAL)									
605,000	41.02	257.8	0	1211	.04431 + j.56045 = .5622 /85°28′47″	464.3 \4°31′13″	.84782 + j.023565 = .8481 /1°35′31″	36.85 + j 244.92 = 247.67 /81°26′37″	−.000 01 + j.001149 = .001149 \90°29′03″
715,500	35.85	255.5	0	1226	.03917 + j.56103 = .5624 /86°00′28″	458.7 \3°59′37″	.84735 + j.020846 = .8476 /1°24′32″	32.196 + j 242.62 = 244.8 /82°26′28″	−.000 01 + j.00 163 = .001163 \90°25′43″
795,000	32.70	254	0	1235	.03598 + j.56247 = .5624 /86° 9′55″	455.4 \3°40′04″	.84715 + j.019155 = .8474 /1°17′43″	29.36 + j 241.1 = 242.9 /83°03′25″	−.00001 + j.001171 = .001171 \90°23′19″
954,000	28.37	251.5	0	1256	.03165 + j.562922 = .5638 /86°46′55″	448.98 \3°13′02″	.84612 + j.016893 = .8463 /1°08′38″	25.432 + j 238.628 = 240 /83°54′43″	−.000 007 + j.001191 = .001191 \90°20′52″

* Since two 50,000 kv.a. banks of transformers will be required at each end the corresponding values for impedance will be half these amounts.

$$A = \frac{\sinh \theta/\theta}{\tanh \theta/\theta} = \frac{0.964\,\underline{/0^\circ 24' 00''}}{1.0785\,\underline{\diagdown 0^\circ 52' 48''}}$$

$$= 0.8939\,\underline{/1^\circ 16' 48''}$$

$$a_1 = 0.8937$$

$$a_2 = 0.01996$$

$$B = Z\frac{\sinh \theta}{\theta} = 181.54\underline{/78^\circ 59' 46''} \times 0.964\underline{/0^\circ 24' 00''}$$

$$= 175.0\angle 79°23'46''$$

$$b_1 = 32.2 \text{ ohms}$$

$$b_2 = 172 \text{ ohms}$$

$$C = Y\frac{\sinh\theta}{\theta} = 0.001211\angle 90° \times 0.964\angle 0°24'00''$$

$$= 0.001167 \diagdown 90°24'00''$$

$$C_1 = -0.000008 \text{ mho}$$

$$C_2 = 0.001167 \text{ mho}$$

The auxiliary constants as obtained graphically and by exact mathematical solution, are given in Table *ZZ*. It is thus seen that the Kennelly Charts, although primarily intended for correcting the linear impedance and the linear admittance of circuits for the equivalent π solution, are highly adaptable to determining the values of the auxiliary constants to a very close degree of accuracy. The use of these charts for obtaining auxiliary constants requires more arithmetical work than the use of the Wilkinson Charts. For instance the hybolic angle, $\theta = \sqrt{\dot{Z}\dot{Y}}$, of the circuit must first be calculated before the charts can be employed. The results, read from charts, must then be multiplied by the impedance and the admittance of the circuit for obtaining auxiliary constants B and C. Auxiliary constant A cannot be taken directly from a single Kennelly Chart. To obtain this auxiliary constant from these charts it is necessary to divide the values read from two of these charts since

$$A = \frac{\sinh\theta/\theta}{\tanh\theta/\theta}$$

Chart $\tanh\theta/\theta$ is constructed for angles up to and including 0.50 polar values. This makes it adapted to angles up to 1.0 polar value when used for determining correcting factors for the equivalent π solution. This is for the reason that for obtaining such correcting factors we enter this chart with $\theta/2$. However for obtaining auxiliary constant A by means of values read from these charts we must enter this chart with θ in place of $\theta/2$. This limits the use of the Kennelly Charts for obtaining auxiliary constant A to circuit angles not exceeding 0.5 polar values. In case the circuit angle has a polar value greater than 0.5, Wilkinson Chart A may be used provided the line is not over 300 miles long. If the circuit is over 300 miles long the auxiliary constants should be determined by mathematical calculation.

In the following discussion the calculated values for the auxiliary constants will be used, since exact results are required for the purpose of comparing the results with those obtained by the approximate method, a description of which follows the complete solution.

NORMAL LOAD—COMPLETE SOLUTION

The complete solution for normal load is given by Chart XXIII. At the top is illustrated the circuit diagramatically. Underneath this is stated the load conditions, the linear and auxiliary constants for this circuit. The transformer data and method of determining the amperes iron loss, magnetizing current and impedance to the neutral of the lowering transformer are also shown. Actually the impedance of raising and lowering transformers, even when duplicates, is slightly different when the connections are not made to similar taps. This difference is so slight (and so far as the raising transformer is concerned so unimportant) that for simplicity, we are assuming that both raising and lowering transformers have the same impedance. This comprises all the data required for a complete mathematical or graphical solution of this circuit.

Following the data is a complete graphical vector solution of this circuit with symbols placed on all vectors indicating the manner of obtaining their values. At the lower left-hand corner is placed a complete mathematical solution of the problem, which parallels the graphical solution (one method of solution checking the other). In the calculations of the high-voltage circuit the current, in order to include the power-factor, must always be expressed in complex form referred to the vector of reference, as indicated by a dot under the symbol I.

At the lower right-hand corner a method is indicated of determining the transmission loss from the calculated quantities. The loss in the high-tension line can be determined graphically by scaling off the voltage and the current at each end of the high-tension line and measuring the angle between the vectors representing the current and the voltage. The current times the voltage times the cosine of this angle will give the power at the point considered, and the difference between the power as so determined at the two ends of the high-tension line is the line loss. The losses in transformers and condensers are known and stated at the top of the chart.

Table *ZZ*.—Auxiliary Constants for 220-kv. Problem Approximate Solution

	Calculated, per cent	From Wilkinson Chart, per cent	From Kennelly Chart, per cent
a_1	0.893955 = 100	0.892 = 99.78	0.8937 = 99.97
a_2	0.020234 = 100	0.020 = 98.85	0.01996 = 98.65
b_1	32.198 = 100	32.2 = 100	32.2 = 100
b_2	172.094 = 100	173.5 = 100.82	172 = 99.95
c_1	−0.000008 = 100	can't read	−0.000008 = 100
c_2	0.001168 = 100	0.001175 = 100.6	0.001167 = 99.91

The complete vector diagram is constructed as follows: First draw the horizontal line representing E_{LN}, the voltage at the load to neutral. This should be drawn to as large a scale as possible. All other voltage vectors will of course be drawn to the same scale. The vector I_L representing the load current is now drawn to as large a scale as can be used without mixing the current vectors with the voltage vectors. This is drawn at an angle of 31° 47′ from E_{LN} in the lagging direction, corresponding to a lagging load of 85 per cent power-factor. It usually works out that for normal load the power-factor at the receiving end should be slightly lagging and at the sending end slightly leading so that the average power-factor of the line will be close

to unity. This will necessitate a phase modifier in parallel with the load, having approximately the capacity of the lagging kv.a. in the load.

The lagging kv.a. in the load is equal to the kv.a. of the load times the sine of the angle of the load. In this case it is $88{,}235 \times \sin 31° 47' = 46{,}500$ kv.a. The vector diagram is constructed on the basis of a 45,000 kv.a. condenser in parallel with the load. This condenser has a power loss of 4.72 amp. to neutral and since this is in phase with the load voltage, we trace from the end of the load current vector horizontally to the right a distance representing 4.72 amp. by the current scale. The current per terminal for the condenser is 118.09 amp. so that the leading component of the current input of the condenser is 118.00 amp. Since this is leading it is drawn vertically upward from the last point determined. Actually we will not need to determine the 118 amp. leading component, but will complete the solid black condenser triangle, since the length of the input line is 118.09 amp. To the vector sum of load and condenser currents thus determined we now add the leakage current of the lowering transformers, the lagging component of which materially effects the capacity of the phase modifiers required because of its nearly direct opposition to it under load. We have assumed that the leakage current required by the lowering transformers will be supplied by the phase modifier on account of its close electrical proximity to the lowering transformers. On this assumption the triangle representing this transformer leakage will be located as indicated. There is a loss current of 1.85 amp. in phase with the load voltage and a magnetizing current of 13.9 amp. in lagging quadrature with the load voltage. We thus find that the current I_R at the receiving end of the line is 204.17 amp., lagging 5° 1′ 16″ behind the load voltage. In this case the magnetizing current of the lowering transformer reduces the effective capacity of the phase modifier by an amount of 13.9 amp., that is by 5.3 per cent of the total capacity of the lowering transformers.

We next determine the voltage at the high-voltage side of the lowering transformers; that is the voltage E_{RN} at the receiving end of the transmission line. Knowing the resistance and reactance of the lowering transformer banks to neutral and the current I_R, the transformer resistance voltage drop is plotted in phase with the current I_R and the reactance voltage drop in quadrature with the resistance drop as indicated. The voltage E_{SN} at the sending end of the transmission line is next determined by applying auxiliary constants A and B to the voltage and current respectively of the receiving end.

The base of the impedance triangle for the high-voltage line $I_R \times b_1$ represents the resistance drop of the high-voltage line in phase with the receiving end current. In quadrature to this is the reactance volts drop of the line $I_R \times b_2$. The voltage at the sending end is thus determined to be 131,858 volts which corresponds to slightly less than 230,000 volts between conductors. An arc of a circle corresponding to the voltage to be maintained at the sending end will serve as a guide in determining the proper capacity condenser necessary to maintain this sending-end voltage. An increase in condenser capacity rotates the vector I_R in a counter-clockwise direction, swinging the line impedance triangle also in a counter-clockwise direction thus decreasing the voltage E_{SN} and reducing the line drop. A decrease in condenser capacity rotates the vector I_R in a clockwise direction, swinging the line impedance triangle also in a clockwise direction, thus increasing the voltage E_{SN} and increasing the line drop. Thus the effect upon line voltage drop may be readily determined for condensers of various capacities.

The next step is to determine the current at the sending end. This is done by applying auxiliary constants A and C to the current and voltage respectively of the receiving end. It will be noted that the charging current is drawn as leading by 90 degrees the high-tension voltage at the receiving end, which voltage is taken as the vector of reference as in previous discussions. The current at the sending end is thus determined to be 220.34 amp. leading the vector of reference by 35° 12′. The impedance triangle for the raising transformers may now be drawn in, the resistance drop being drawn parallel with I_S. This then gives the voltage at the generators. The current at the generators is determined by adding vectorally to I_S the leakage of the raising transformers. It is assumed that the raising transformers will receive their excitation from the generators, in which case the leakage triangle will occupy the position shown, resulting in a current at the generators of 218.88 amp.

NORMAL LOAD—APPROXIMATE SOLUTION

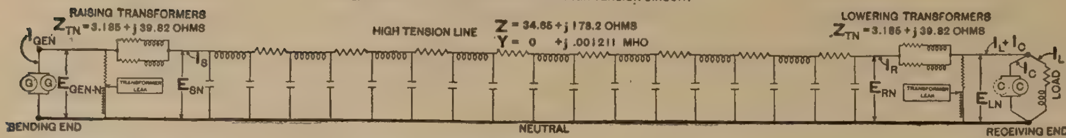
The approximate solution for normal load is given in Chart XXIV. It differs from the complete solution in that the impedance of the lowering transformers is added to and considered as a part of the line impedance so that there are no transformer impedance triangles to construct. It differs also in that, in the case illustrated, the conditions at the sending end only are obtained, whereas in the complete diagram the conditions at both sending end and generators were determined. If the condition at the generators rather than the condition at the sending end is required, the impedance of the raising transformers would also be added to that of the line, the general construction of the diagram remaining the same as for the complete solution.

If it is not necessary to know conditions at both sides of the raising and lowering transformer banks, then it will be seen from a comparison of the two diagrams that the approximate solution will be simpler, although the results will be somewhat incorrect. For instance, for the 220-kv. problem illustrated, the errors in the results will, according to tabulations in the lower right-hand corner, vary from 0.88 to 2.38 per cent. If the losses in condensers and transformers were not added to the load (as they are in both these complete and approximate methods) and the transformer magnetizing current were not taken into account, (as it also

CHART XXIII—220 KV. PROBLEM—NORMAL LOAD

(COMPLETE SOLUTION)

(LOW TENSION VALUES REFERRED TO THE HIGH TENSION CIRCUIT)



NORMAL LOAD

PER 3 PHASE CIRCUIT	PER PHASE TO NEUTRAL
$KV\text{-}A_L$ = 88.235	$KV\text{-}A_{LN}$ = 29.412
KW_L = 75.000	KW_{LN} = 25.000
PF_L = 85% LAG.	PF_{LN} = 85% LAG.
E_L = 220.000	E_{LN} = 127.020
I_L = 231 55	I_{LN} = 231 55

60 CYCLES

LINEAR CONSTANTS

Z = 34.65 + j 178.2 OHMS

Y = 0 + j .001211 MHO

AUXILIARY CONSTANTS

$(A) = (a_1 + j\,a_2) = \cosh\theta = .893{,}955 + j\,.020{,}234 = .89418\,\underline{/1°17'47''}$

$(B) = (b_1 + j\,b_2) = Z\,\frac{\sinh\theta}{\theta} = \sqrt{\frac{Z}{Y}}\,\sinh\theta = 32.198 + j\,172.094$ OHMS

$(C) = (c_1 + j\,c_2) = Y\,\frac{\sinh\theta}{\theta} = \frac{1}{\sqrt{\frac{Z}{Y}}}\,\sinh\theta = -.000{,}008 + j\,.001{,}168$ MHO.

WHERE $\theta = \sqrt{ZY}$

TRANSFORMERS

(TWO BANKS IN PARALLEL AT EACH END OF THE LINE)

ON BASIS OF 100,000 KV-A RATING FOR TWO BANKS:

RESISTANCE VOLTS	= 0.658 %
REACTANCE VOLTS	= 8.225 %
MAGNETIZING CURRENT	= 5.300 %
IRON LOSS	= 0.705 %

VALUES TO NEUTRAL

$KV\text{-}A_{TN}$ = 33.333. E_{TN} = 127,020. I_{TN} = 262.4

$R_{TN} = \frac{.00658 \times 127{,}020}{262.4}$ = 3.185 OHMS RESISTANCE

$X_{TN} = \frac{.08225 \times 127{,}020}{262.4}$ = 39.82 OHMS REACTANCE

MAGNETIZING CURRENT = $\frac{.0530 \times 33{,}333{,}333}{127{,}020}$ = 13.9 AMPS AT 127,020 VOLTS

IRON LOSS = $\frac{.00705 \times 33{,}333{,}333}{127{,}020}$ = 1.85 AMPS AT 127,020 VOLTS

IRON LOSS = 235 KW TO NEUTRAL

NOTE—FROM THE VECTOR DIAGRAM IT MAY BE SEEN THAT THE RAISING TRANSFORMERS WILL BE EXCITED BY A VOLTAGE EQUIVALENT TO 129.916—THE LEAKAGE CURRENT REQUIRED TO EXCITE THE RAISING TRANSFORMERS WILL THEREFORE BE

MAGNETIZING CURRENT = 13.6 AMPS. AT 129.916 VOLTS
IRON LOSS = 1.81 AMPS. AT 129.916 VOLTS

CONDENSER

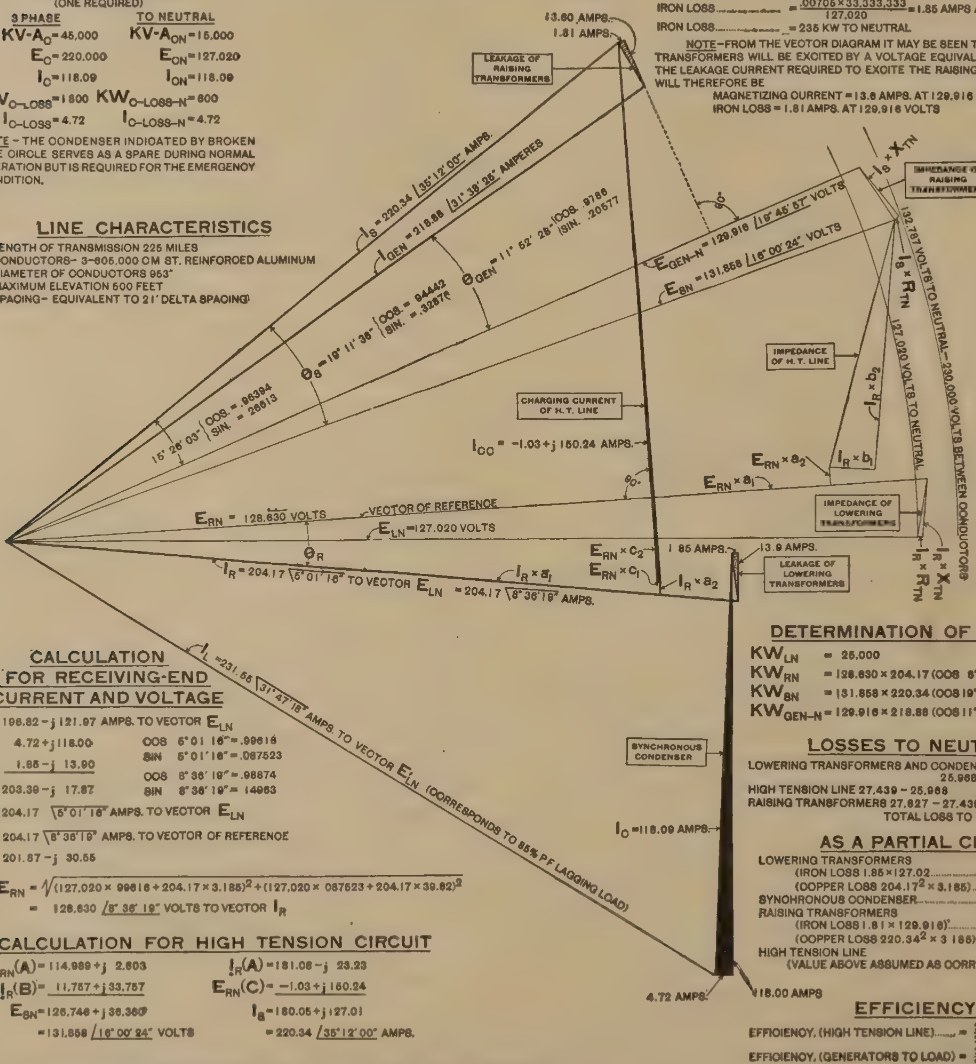
(ONE REQUIRED)

3 PHASE	TO NEUTRAL
$KV\text{-}A_C$ = 45.000	$KV\text{-}A_{CN}$ = 15.000
E_C = 220.000	E_{CN} = 127.020
I_C = 118.09	I_{CN} = 118.09
KW_{C-LOSS} = 1800	$KW_{C-LOSS-N}$ = 600
I_{C-LOSS} = 4.72	$I_{C-LOSS-N}$ = 4.72

NOTE – THE CONDENSER INDICATED BY BROKEN LINE CIRCLE SERVES AS A SPARE DURING NORMAL OPERATION BUT IS REQUIRED FOR THE EMERGENCY CONDITION.

LINE CHARACTERISTICS

LENGTH OF TRANSMISSION 225 MILES
CONDUCTORS – 3–605,000 CM ST. REINFORCED ALUMINUM
DIAMETER OF CONDUCTORS 953"
MAXIMUM ELEVATION 500 FEET
SPACING – EQUIVALENT TO 21' DELTA SPACING



CALCULATION FOR RECEIVING-END CURRENT AND VOLTAGE

I_L = 196.82 − j 121.97 AMPS. TO VECTOR E_{LN}

I_C = 4.72 + j 118.00 COS 5°01'16" = .99616

I_T = 1.85 − j 13.90 SIN 5°01'16" = .087523

I_R = 203.39 − j 17.87 COS 8°36'19" = .98874 SIN 8°36'19" = .14963

= 204.17 $\overline{\backslash 5°01'16''}$ AMPS. TO VECTOR E_{LN}

= 204.17 $\overline{\backslash 8°36'19''}$ AMPS. TO VECTOR OF REFERENCE

= 201.87 − j 30.55

$E_{RN} = \sqrt{(127{,}020 \times .99616 + 204.17 \times 3.185)^2 + (127{,}020 \times .087523 + 204.17 \times 39.82)^2}$

= 128,630 $\underline{/8°36'19''}$ VOLTS TO VECTOR I_R

CALCULATION FOR HIGH TENSION CIRCUIT

$E_{RN}(A)$ = 114,989 + j 2,603	$I_R(A)$ = 181.08 − j 23.23
$I_R(B)$ = 11,757 + j 33,757	$E_{RN}(C)$ = −1.03 + j 150.24
E_{SN} = 126,746 + j 36,360	I_S = 180.05 + j 127.01
= 131,858 $\underline{/16°00'24''}$ VOLTS	= 220.34 $\underline{/35°12'00''}$ AMPS.

CALCULATION FOR GENERATOR VOLTAGE AND CURRENT

$E_{GEN-N} = \sqrt{(131{,}858 \times .94442 + 220.34 \times 3.185)^2 + (131{,}858 \times .32876 - 220.34 \times 39.82)^2}$

= 129,916 $\underline{/15°26'03''}$ VOLTS TO VECTOR I_S

= 129,916 $\underline{/19°45'57''}$ VOLTS

220.34 (.96394 + j .26613)
= 212.39 + j 58.64
= 1.81 − j 13.60 (LEAKAGE OF RAISING TRANSFORMERS)

I_{GEN-N} = 214.20 + j 45.04

= 218.88 $\underline{/11°52'26''}$ AMPERES TO VECTOR E_{GEN}

= 218.88 $\underline{/31°38'26''}$ AMPERES

$KV\text{-}A_S$ = 131.858 × 220.34 × 3 = 87,163 PER 3 PHASE CIRCUIT

$KV\text{-}A_{GEN}$ = 129.916 × 218.88 × 3 = 85,308 PER 3 PHASE CIRCUIT

$KV\text{-}A_{CC}$ = 131 858 × 150.24 × 3 = 59,431 PER 3 PHASE CIRCUIT

DETERMINATION OF LOSSES

KW_{LN} = 25,000

KW_{RN} = 128.630 × 204.17 (COS 8°36'19") = 25,968

KW_{SN} = 131.858 × 220.34 (COS 19°11'36") = 27,439

KW_{GEN-N} = 129.916 × 218.88 (COS 11°52'26") = 27,827

LOSSES TO NEUTRAL

LOWERING TRANSFORMERS AND CONDENSER 25,968 − 25,000	= 968
HIGH TENSION LINE 27,439 − 25,968	= 1471
RAISING TRANSFORMERS 27,827 − 27,439	= 388
TOTAL LOSS TO NEUTRAL	= 2827

AS A PARTIAL CHECK

LOWERING TRANSFORMERS	
(IRON LOSS 1.85 × 127.02)	= 235
(COPPER LOSS 204.17² × 3.185)	= 132
SYNCHRONOUS CONDENSER	= 600
RAISING TRANSFORMERS	
(IRON LOSS 1.81 × 129.916)	= 235
(COPPER LOSS 220.34² × 3 185)	= 154
HIGH TENSION LINE	
(VALUE ABOVE ASSUMED AS CORRECT	= 1471
	2827

EFFICIENCY

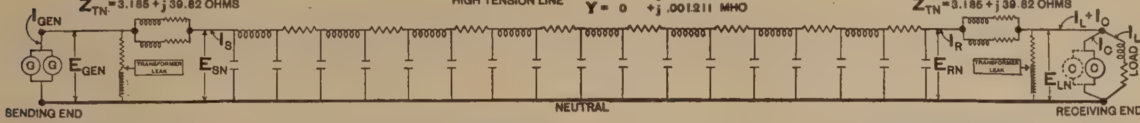
EFFICIENCY, (HIGH TENSION LINE) = $\frac{25{,}968}{27{,}439}$ = 94.64 %

EFFICIENCY, (GENERATORS TO LOAD) = $\frac{25{,}000}{27{,}827}$ = 89.84 %

CHART XXIV—220 KV. PROBLEM—NORMAL LOAD

(APPROXIMATE SOLUTION)

THIS APPROXIMATE SOLUTION ASSUMES THAT THE IMPEDANCE OF THE LOWERING TRANSFORMERS MAY BE ADDED TO THE LINE IMPEDANCE AND TREATED AS THOUGH IT WERE DISTRIBUTED LINE IMPEDANCE--THIS ASSUMPTION SIMPLIFIES THE SOLUTION AT THE EXPENSE OF ACCURACY (SEE LOWER RIGHT HAND CORNER OF PAGE; ALSO TEXT).--THE SOLUTION BELOW IS BASED UPON THE VOLTAGE BEING HELD CONSTANT AT THE LOAD SIDE OF THE LOWERING TRANSFORMERS AND AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS.--IF THE VOLTAGE IS TO BE HELD CONSTANT AT THE GENERATOR BUS, THE IMPEDANCE OF THE RAISING TRANSFORMERS MUST ALSO BE ADDED TO THAT OF THE LINE--ALL LOW TENSION VALUES ARE REFERRED TO THE HIGH TENSION CIRCUIT.



NORMAL LOAD

PER 3 PHASE CIRCUIT	PER PHASE TO NEUTRAL
$KV\text{-}A_L$ = 88.235	$KV\text{-}A_{LN}$ = 29.412
KW_L = 75.000	KW_{LN} = 25.000
PF_L = 85% LAG.	PF_{LN} = 85% LAG.
E_L = 220.000	E_{LN} = 127.020
I_L = 231.55	I_{LN} = 231.55

60 CYCLES

CONDENSER

(ONE REQUIRED)

3 PHASE	TO NEUTRAL
$KV\text{-}A_C$ = 45.000	$KV\text{-}A_{CN}$ = 15.000
E_C = 220.000	E_{CN} = 127.020
I_C = 118.09	I_{CN} = 118.09
$KW_{C\text{-}LOSS}$ = 1800	$KW_{C\text{-}LOSS\text{-}N}$ = 600
$I_{C\text{-}LOSS}$ = 4.72	$I_{C\text{-}LOSS\text{-}N}$ = 4.72

NOTE – THE CONDENSER INDICATED BY BROKEN LINE CIRCLE SERVES AS A SPARE DURING NORMAL OPERATION BUT IS REQUIRED FOR THE EMERGENCY CONDITION.

LINEAR CONSTANTS

Z = 37.835 + j 218.02 OHMS ★
Y = 0 + j .001211 MHO

★ THIS INCLUDES IMPEDANCE OF LOWERING TRANSFORMERS

AUXILIARY CONSTANTS

$(A) = (a_1 + j a_2) = \cosh\theta = .870783 + j\,.021911$

$(B) = (b_1 + j b_2) = Z \dfrac{\sinh\theta}{\theta} = \sqrt{\dfrac{Z}{Y}} \sinh\theta = 34.5653 + j\,208.83$ OHMS

$(C) = (c_1 + j c_2) = Y \dfrac{\sinh\theta}{\theta} = \dfrac{1}{\sqrt{\dfrac{Z}{Y}}} \sinh\theta = -.000{,}009 + j\,.001158$ MHO.

WHERE $\theta = \sqrt{ZY}$

TRANSFORMERS

(TWO BANKS IN PARALLEL AT EACH END OF THE LINE)

ON BASIS OF 100,000 KV-A RATING FOR TWO BANKS:

RESISTANCE VOLTS	= 0.658 %
REACTANCE VOLTS	= 8.225 %
MAGNETIZING CURRENT	= 5.300 %
IRON LOSS	= 0.705 %

VALUES TO NEUTRAL

$KV\text{-}A_{TN}$ = 33.333. E_{TN} = 127.020. I_{TN} = 262.4

$R_{TN} = \dfrac{.00658 \times 127.020}{262.4}$ = 3.185 OHMS RESISTANCE

$X_{TN} = \dfrac{.08225 \times 127.020}{262.4}$ = 39.82 OHMS REACTANCE

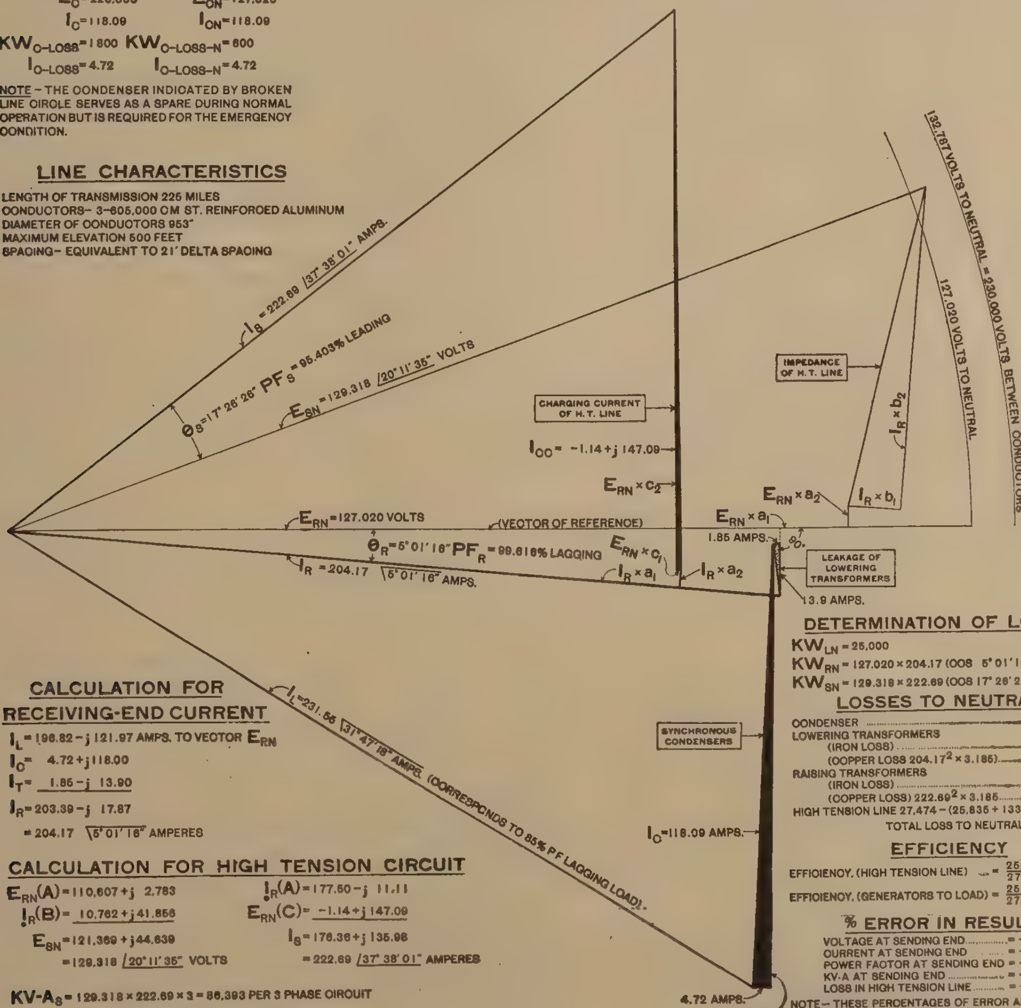
MAGNETIZING CURRENT = $\dfrac{.0530 \times 33.333.333}{127.020}$ = 13.9 AMPS AT 127.020 VOLTS

IRON LOSS = $\dfrac{.00705 \times 33.333.333}{127.020}$ = 1.85 AMPS AT 127.020 VOLTS

IRON LOSS = 235 KW TO NEUTRAL

LINE CHARACTERISTICS

LENGTH OF TRANSMISSION 225 MILES
CONDUCTORS– 3–605,000 CM ST. REINFORCED ALUMINUM
DIAMETER OF CONDUCTORS .953"
MAXIMUM ELEVATION 500 FEET
SPACING– EQUIVALENT TO 21' DELTA SPACING



CALCULATION FOR RECEIVING-END CURRENT

I_L = 196.82 − j 121.97 AMPS. TO VECTOR E_{RN}
I_C = 4.72 + j 118.00
I_T = 1.85 − j 13.90
I_R = 203.39 − j 17.87
= 204.17 /5° 01' 16" AMPERES

CALCULATION FOR HIGH TENSION CIRCUIT

$E_{RN}(A)$ = 110.607 + j 2.783	$I_R(A)$ = 177.50 − j 11.11
$I_R(B)$ = 10.762 + j 41.856	$E_{RN}(C)$ = −1.14 + j 147.09
E_{SN} = 121.369 + j 44.639	I_S = 176.36 + j 135.98
= 129.318 /20° 11' 35" VOLTS	= 222.69 /37° 38' 01" AMPERES

$KV\text{-}A_S$ = 129.318 × 222.69 × 3 = 86.393 PER 3 PHASE CIRCUIT
$KV\text{-}A_{CC}$ = 129.318 × 147.09 × 3 = 57.064 PER 3 PHASE CIRCUIT

DETERMINATION OF LOSSES

KW_{LN} = 25.000
KW_{RN} = 127.020 × 204.17 (COS 5° 01' 16") = 25.835
KW_{SN} = 129.318 × 222.69 (COS 17° 26' 26") = 27.474

LOSSES TO NEUTRAL

CONDENSER	= 600
LOWERING TRANSFORMERS (IRON LOSS)	= 235
(COPPER LOSS 204.17² × 3.185)	= 133
RAISING TRANSFORMERS (IRON LOSS)	= 235
(COPPER LOSS) 222.69² × 3.185	= 158
HIGH TENSION LINE 27.474 − (25.835 + 133)	= 1506
TOTAL LOSS TO NEUTRAL	= 2867

EFFICIENCY

EFFICIENCY, (HIGH TENSION LINE) = $\dfrac{25.968}{27.474}$ = 94.52

EFFICIENCY, (GENERATORS TO LOAD) = $\dfrac{25.000}{27.867}$ = 89.7%

% ERROR IN RESULTS

VOLTAGE AT SENDING END	= − 1.93 %
CURRENT AT SENDING END	= + 1.06 %
POWER FACTOR AT SENDING END	= + 1.02 %
KV-A AT SENDING END	= − 0.88 %
LOSS IN HIGH TENSION LINE	= + 2.38 %

NOTE – THESE PERCENTAGES OF ERROR ARE BASED UPON THE ASSUMPTION THAT THE COMPLETE METHOD PRODUCES 100% VALUES.–THE MINUS SIGNS SIGNIFY RESULTS TOO LOW; THE PLUS SIGNS RESULTS TOO HIGH.

is in both these methods) the error resulting from the use of the aproximate method would be considerably greater than the above values.

The simplified graphical approximate solution illustrated by Chart XXIV will yield results sufficiently accurate for preliminary work, although for final results it should be supplemented by a mathematical solution and, in cases of very long lines, a complete mathematical solution might be desirable. A complete solution as given by Chart XXIII may be followed as a guide in such cases.

The method of obtaining the auxiliary constants corresponding to the approximate solution is given below. The linear constants of the circuit, including transformer impedance, are determined as follows:

	Resistance (Ohms)	Reactance (Ohms)
Line	34.650	178.20
Transformers	3.185	39.82
Total	37.835	218.02

Dividing these total values by 225 we obtain the following as the impedance per mile of the combined circuit.

$$r = 0.1681 \text{ ohms}$$
$$x = 0.969 \text{ ohms}$$

Table *ZZZ*.—Auxiliary Constants for 220 Kv. Problem, Approximate Solution

Calculated, per cent	From Wilkinson Chart, per cent	From Kennelly Chart, per cent
$a_1 = 0.870783 = 100$	$0.892 = 102.44$ $0.868 = 99.68$ (corrected)	$0.8713 = 100.05$
$a_2 = 0.021911 = 100$	$0.0221 = 100.86$	$0.02206 = 100.68$
$b_1 = 34.5653 = 100$	$34.3 = 99.23$	$34.561 = 99.99$
$b_2 = 208.83 = 100$	$211.2 = 101.14$	$208.92 = 100.04$
$c_1 = -0.000009 = 100$	$-0.00001 = 111.11$	$-0.000009 = 100$
$c_2 = 0.001158 = 100$	$0.001163 = 100.43$	$0.001159 = 100.09$

The admittance per mile is assumed the same as before, namely:

$$b = 5.38 \times 10^{-6} \text{ mho}$$
$$g = 0$$

From Wilkinson's Charts.

$$a_1 = 0.892$$
$$\text{and since } rb = 0.904$$
$$a_2 = 0.221$$
$$b_1 = 34.3 \text{ ohms}$$
$$b_2 = 211.2 \text{ ohms}$$
$$\text{and since } rb^2 = 4.865$$
$$c_1 = -0.000010$$
$$c_2 = 0.001163$$

From Dr. Kennelly's Charts.

$$Z = 37.835 + j\,218.02$$
$$= 221.28 \;\underline{|80°09'23''}$$
$$Y = 0 + j0.001211$$
$$= 0.001211 \;|90°$$
$$ZY = 0.26797 \;\overline{\diagdown 170'09'23''}$$
$$\theta = \sqrt{ZY} = 0.5177 \;\underline{|85°04'41''}$$
$$\text{from Chart XIX } \frac{\text{Sinh } \theta}{\theta} = 0.957 \;\underline{/0.45°}$$
$$= 0.957 \;\underline{/0°27'00''}$$

$$\text{from Chart XXI } \frac{\text{Tanh } \theta}{\theta} = 1.098 \;\overline{\diagdown 1°00'00''}\,*$$
$$A = \frac{\text{Sinh } \theta/\theta}{\text{Tanh } \theta/\theta} = \frac{0.957 \;\underline{/0°27'00''}}{1.098 \;\overline{\diagdown 1°00'00''}}$$
$$= 0.8716 \;\underline{/1°27'00''}$$
$$a_1 = 0.8713$$
$$a_2 = 0.02206$$
$$B = Z\frac{\text{Sinh } \theta}{\theta} = 221.28 \;\underline{|80°09'23''} \times 0.957 \;\underline{/0°27'00''}$$
$$= 211.76 \;\underline{/80°36'23''} \text{ ohms}$$
$$b_1 = 34.561 \text{ ohms}$$
$$b_2 = 208.92 \text{ ohms}$$
$$C = Y\frac{\text{Sinh } \theta}{\theta} = 0.001211 \;|90° \times 0.957 \;\underline{/0°27'00''}$$
$$= 0.0011589 \;\underline{|90°27'00''}$$
$$c_1 = -0.000009$$
$$c_2 = 0.001159$$

The auxiliary constants as obtained graphically and by exact mathematical results are given in Table *ZZZ*.

The same remarks in regard to use of the Kennelly Charts for obtaining the auxiliary constants, as given under the complete solution, also apply when the approximate solution is used. Wilkinson Chart *A*, if used when transformer impedance is added to the line impedance, as in the approximate method, requires a correction to constant a_1. Constant a_2 as read from this chart will be correct but constant a_1 as read from the chart will be too high for the following reason. Constant c_1 accounts for the rise in voltage along the line at zero load due to the charging current flowing through the line inductance adding directly to the sending end voltage. The section of Wilkinson Chart *A* applying to constant a_1 is based upon distance and frequency only, so that values read from this section would be the same for a given distance and frequency regardless of whether or not transformer impedance is included with the line constants. This section of chart *A*, therefore, takes account only of the voltage lowering effect of the charging current flowing through the line inductance. In addition to this, it flows also through the transformer inductance, which further lowers the value of a_1. The value of a_1 read from the chart must therefore be reduced. From the chart, $a_1 = 0.892$ volt corresponding to a voltage rise of 0.108 volt which results from a linear conductance reactance of 178.02 ohms. Actually the reactance of the circuit including lowering transformers is 218.02 ohms or 22.5 per cent greater. Increasing 0.108 volt by 22.5 per cent we get 0.132 volt rise, so that a_1 becomes $1.000 - 0.132 = 0.868$, which is 99.68 per cent of the calculated results.

In the following solutions calculated values for the auxiliary constants are used, since exact results are required for the purpose of comparing the results with those previously obtained by the complete solution.

EMERGENCY LOAD—COMPLETE SOLUTION

The complete solution for emergency load conditions shown by Chart XXV follows the same construction as covered by Chart XXIII for normal load, the difference being that the load is doubled and the condenser capacity for a circuit increased nearly four times.

* This was interpolated since this angle lies beyond the range on this chart.

Thus to force double the amount of power through the line and transformer impedance, with the same voltage drop, it is necessary in this case, nearly to quadruple the condenser capacity per circuit. Thus to meet the emergency condition nearly double the total condenser capacity will be required. This large increase in condenser capacity necessitated drawing the current vectors to one half the scale used for current vectors in the normal load diagram.

EMERGENCY LOAD—APPROXIMATE SOLUTION

The approximate solution for emergency load shown by Chart XXVI follows the same construction as in Chart XXIV for normal load with the exception of increased load and condenser capacity.

ZERO LOAD—COMPLETE SOLUTION

The complete solution for zero load is shown by Chart XXVII. In this case the load is made up of a lagging phase modifier load and the leakage of the lowering transformers. The same constructions are used as for the other complete solutions.

ZERO LOAD—APPROXIMATE SOLUTION

The approximate solution for zero load is shown by Chart XXVIII. It may be seen from the tabulated errors that this approximate method produces at zero load larger errors than the corresponding errors for loaded conditions. This is usually of little importance, however, as the light load conditions are generally not important.

PHASE MODIFIER CURVES

Frequently the normal and maximum amount of power to be transmitted is known; that is the transmission line, condensers and transformers are designed for a certain maximum load and it is of little importance what condenser capacity would be required for other loads or for various sending end voltages. At other times, especially in preliminary surveys, such data may be very necessary.

In Fig. 70 are plotted curves* showing the phase modifier capacity required to produce certain voltages at the sending end corresponding to various receiving-end loads at 85 per cent power-factor and 220 kv. At 85 per cent power-factor and 220-kv. 200,000 kw. is approximately the maximum amount of power which may be transmitted through the lowering transformers and over this line of three 605,000 circ. mil cables if the sending-end voltage is not permitted to exceed 230 kv. This is indicated by the fact that the curve corresponding to this load becomes flat when it reaches the 230 kv. horizontal line. To deliver this maximum load at 220 kv. through the impedance of this line will require a total condenser capacity of about 300,000 kv.a. The economic capacity of the line is reached at loads very much below the maximum theoretical limit of 200,000 kw.

The sending-end voltages corresponding to various capacities of phase modifiers in parallel with different receiving-end loads for drawing curves such as shown by Fig. 70 are most readily obtained by the following graphical procedure. After auxiliary constants A and B for the circuit under investigation have been determined (preferably through the medium of both the Wilkinson and Kennelly Charts), a tabulation of the current to neutral corresponding to each load for which curves are desired is made. A further tabulation of current to neutral for condensers of various capacities is made. The current to neutral which represents the loss in the various condensers, is also tabulated. The resistance, reactance, iron loss and magnetizing currents of the transformer banks to neutral should also be determined for all capacity transformer banks required. With the above data tabulated any draftsman can be instructed how to draw vector diagrams of the circuit to determine the sending-end voltages corresponding to the various receiving-end loads and different phase modifier capacities.

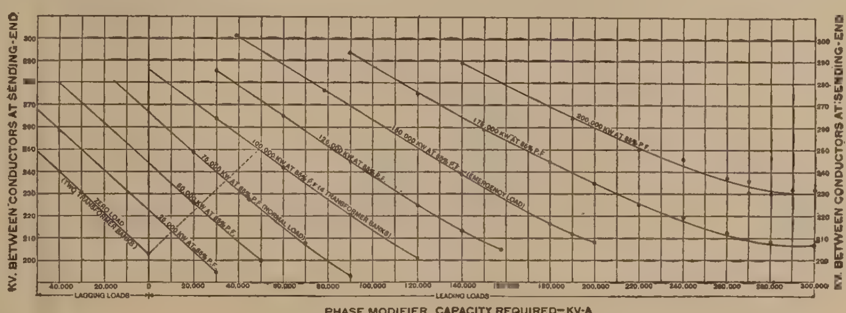


Fig. 70.—Phase modifier capacity required to maintain constant receiver voltage.

These curves indicate for a constant load power-factor of 85 per cent lagging and constant load voltage of 220 kv., the amount of energy which may be delivered to the load over one 225-mile, 60-cycle, three-phase circuit consisting of three 605,000 circ. mil aluminum-steel conductors corresponding to various voltages between conductors at the high-tension side of the raising transformers. The values by which these curves were drawn were determined graphically. For 230 kv. at the sending end the maximum amount of power which can be transmitted is approximately 200,000 kw. and to force this amount of power through the line impedance will require approximately 300,000 kv.a. capacity in phase modifiers.

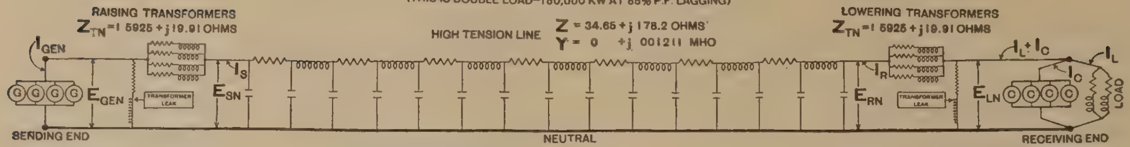
The graphical method used in determining the values to plot the curves of Fig. 70, is illustrated by Fig. 71. Three solutions are illustrated, two with condensers of different sizes and one without condensers. Three such solutions for each load will usually be sufficient to locate the curve, although more points were calculated for drawing the curves of Fig. 70. This method of obtaining condenser capacities corresponding to sending end voltages is a cut and try method. It has one important advantage in its favor. That is, the results check each other, so that an error in one of the graphical constructions corresponding to a given load

* Such curves were suggested by Mr. F. W. Peek, Jr.: Practical Calculations of Long Distance Transmission Line Characteristics. *General Electrical Review*, June, 1913, p. 430.

CHART XXV—220 KV. PROBLEM—EMERGENCY LOAD

(COMPLETE SOLUTION)

(THIS IS DOUBLE LOAD—150,000 KW AT 85% P.F. LAGGING)



EMERGENCY LOAD

PER 3 PHASE CIRCUIT	PER PHASE TO NEUTRAL
$KV\text{-}A_L$ = 176.470	$KV\text{-}A_{LN}$ = 58.824
KW_L = 150,000	KW_{LN} = 50.000
PF_L = 85% LAG.	PF_{LN} = 85% LAG.
E_L = 220.000	E_{LN} = 127.020
I_L = 463.1	I_{LN} = 463.1

60 CYCLES

TRANSFORMERS

(FOUR BANKS IN PARALLEL AT EACH END OF THE LINE)

R_{TN} = 1.5925 OHMS RESISTANCE X_{TN} = 19.91 OHMS REACTANCE

MAGNETIZING CURRENT = 27.8 AMPS. AT 127.020 VOLTS
IRON LOSS .... = 3.70 AMPS. AT 127.020 VOLTS
IRON LOSS .... = 470 KW TO NEUTRAL

MAGNETIZING CURRENT = 26.46 AMPS. AT 133.552 VOLTS
IRON LOSS .... = 3.52 AMPS AT 133.552 VOLTS

LINEAR CONSTANTS

Z = 34.65 + j 178.2 OHMS
Y = 0 + j .001211 MHO

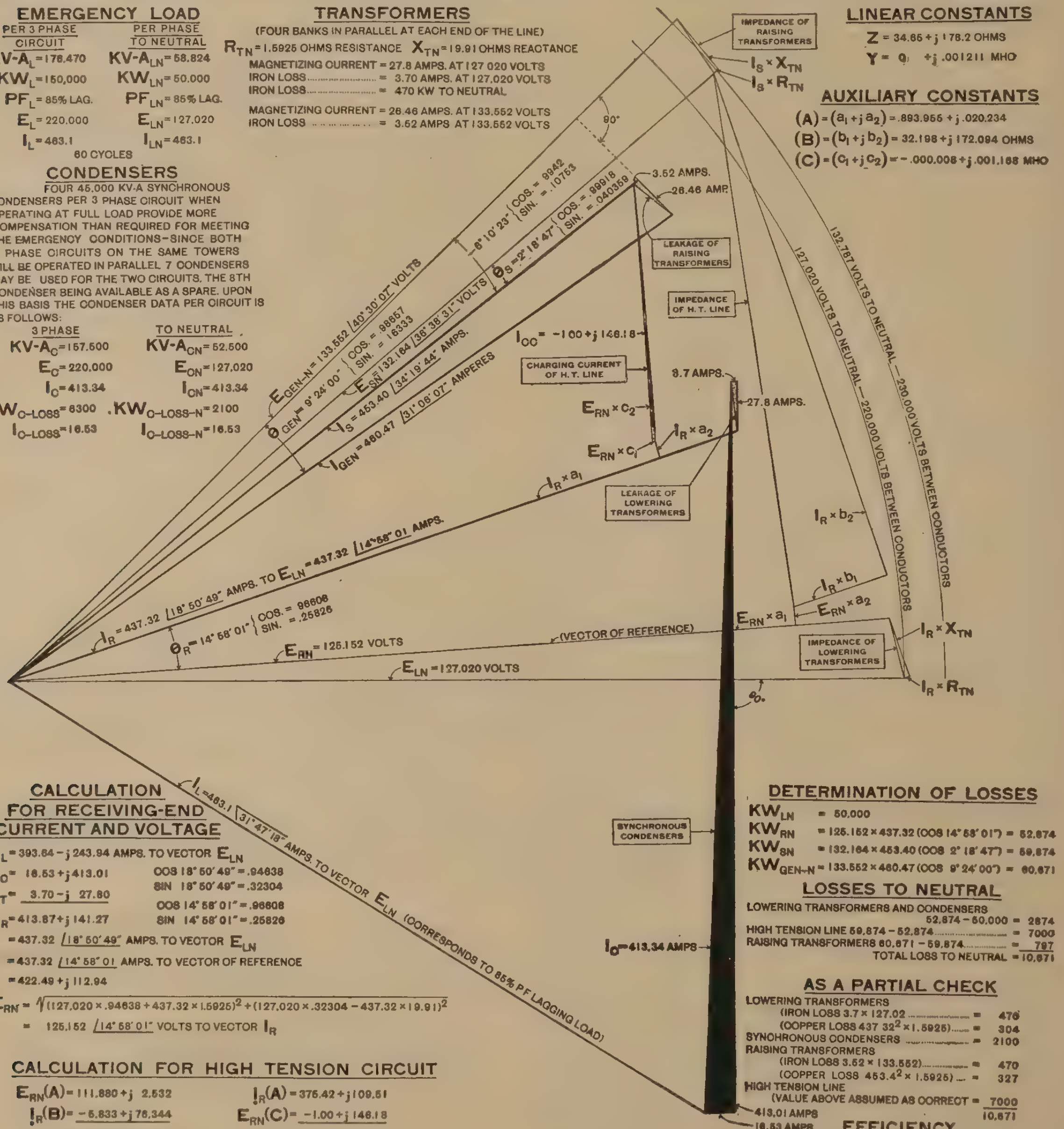
AUXILIARY CONSTANTS

$(A) = (a_1 + j a_2) = .893.955 + j .020.234$
$(B) = (b_1 + j b_2) = 32.198 + j 172.094$ OHMS
$(C) = (c_1 + j c_2) = -.000.008 + j .001.168$ MHO

CONDENSERS

FOUR 45,000 KV-A SYNCHRONOUS CONDENSERS PER 3 PHASE CIRCUIT WHEN OPERATING AT FULL LOAD PROVIDE MORE COMPENSATION THAN REQUIRED FOR MEETING THE EMERGENCY CONDITIONS—SINCE BOTH 3 PHASE CIRCUITS ON THE SAME TOWERS WILL BE OPERATED IN PARALLEL 7 CONDENSERS MAY BE USED FOR THE TWO CIRCUITS, THE 8TH CONDENSER BEING AVAILABLE AS A SPARE. UPON THIS BASIS THE CONDENSER DATA PER CIRCUIT IS AS FOLLOWS:

3 PHASE	TO NEUTRAL
$KV\text{-}A_C$ = 157.500	$KV\text{-}A_{CN}$ = 52.500
E_C = 220.000	E_{CN} = 127.020
I_C = 413.34	I_{CN} = 413.34
KW_{C-LOSS} = 6300	$KW_{C-LOSS-N}$ = 2100
I_{C-LOSS} = 16.53	$I_{C-LOSS-N}$ = 16.53



CALCULATION FOR RECEIVING-END CURRENT AND VOLTAGE

I_L = 393.64 − j 243.94 AMPS. TO VECTOR E_{LN}
I_C = 16.53 + j 413.01 COS 18° 50′ 49″ = .94638
SIN 18° 50′ 49″ = .32304
I_T = 3.70 − j 27.80
COS 14° 58′ 01″ = .96606
I_R = 413.87 + j 141.27 SIN 14° 58′ 01″ = .25826
= 437.32 /18° 50′ 49″ AMPS. TO VECTOR E_{LN}
= 437.32 /14° 58′ 01 AMPS. TO VECTOR OF REFERENCE
= 422.49 + j 112.94

$$E_{RN} = \sqrt{(127.020 \times .94638 + 437.32 \times 1.5925)^2 + (127.020 \times .32304 - 437.32 \times 19.91)^2}$$

= 125.152 /14° 58′ 01″ VOLTS TO VECTOR I_R

DETERMINATION OF LOSSES

KW_{LN} = 50.000
KW_{RN} = 125.152 × 437.32 (COS 14° 58′ 01″) = 52.874
KW_{SN} = 132.164 × 453.40 (COS 2° 18′ 47″) = 59.874
KW_{GEN-N} = 133.552 × 460.47 (COS 9° 24′ 00″) = 60.671

LOSSES TO NEUTRAL

LOWERING TRANSFORMERS AND CONDENSERS 52.874 − 50.000 = 2874
HIGH TENSION LINE 59.874 − 52.874 .... = 7000
RAISING TRANSFORMERS 60.671 − 59.874 .... = 797
TOTAL LOSS TO NEUTRAL = 10.671

AS A PARTIAL CHECK

LOWERING TRANSFORMERS
(IRON LOSS 3.7 × 127.02 .... = 470
(COPPER LOSS 437.32² × 1.5925) .... = 304
SYNCHRONOUS CONDENSERS .... = 2100
RAISING TRANSFORMERS
(IRON LOSS 3.52 × 133.552) .... = 470
(COPPER LOSS 453.4² × 1.5925) .... = 327
HIGH TENSION LINE
(VALUE ABOVE ASSUMED AS CORRECT = 7000
10.671

EFFICIENCY

EFFICIENCY (HIGH TENSION LINE) .... = $\frac{52.874}{59.874}$ = 88.31%
EFFICIENCY (GENERATORS TO LOAD) = $\frac{50.000}{60.671}$ = 82.41%

CALCULATION FOR HIGH TENSION CIRCUIT

$E_{RN}(A)$ = 111.880 + j 2.532 $I_R(A)$ = 375.42 + j 109.51
$I_R(B)$ = −5.833 + j 76.344 $E_{RN}(C)$ = −1.00 + j 146.18
E_{SN} = 106.047 + j 78.876 I_S = 374.42 + j 255.69
= 132.164 /36° 38′ 31″ VOLTS = 453.40 /34° 19′ 44″ AMPERES

CALCULATION FOR GENERATOR VOLTAGE AND CURRENT

$$E_{GEN-N} = \sqrt{(132.164 \times .99918 + 453.4 \times 1.5925)^2 + (132.164 \times .040359 + 453.4 \times 19.91)^2}$$

= 133.552 /6° 10′ 23″ VOLTS TO VECTOR I_S
= 133.552 /40° 30′ 07″ VOLTS

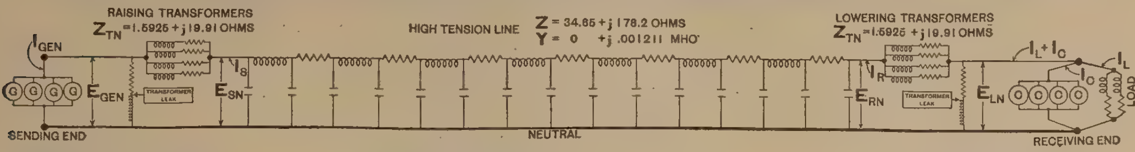
453.4 (.9942 − j .10753)
= 450.77 − j 48.75
= 3.52 − j 26.46 (LEAKAGE OF RAISING TRANSFORMERS)
I_{GEN-N} = 454.29 − j 75.21
= 460.47 /9° 24′ 00″ AMPERES TO VECTOR E_{GEN}
= 460.47 /31° 06′ 07″ AMPERES

$KV\text{-}A_S$ = 132.164 × 453.40 × 3 = 179.769 PER 3 PHASE CIRCUIT
$KV\text{-}A_{GEN}$ = 133.552 × 460.47 × 3 = 184.490 PER 3 PHASE CIRCUIT
$KV\text{-}A_{CC}$ = 132.164 × 146.18 × 3 = 57.959 PER 3 PHASE CIRCUIT

CHART XXVI—220 KV. PROBLEM—EMERGENCY LOAD

(APPROXIMATE SOLUTION)

THIS APPROXIMATE SOLUTION ASSUMES THAT THE IMPEDANCE OF THE LOWERING TRANSFORMERS MAY BE ADDED TO THE LINE IMPEDANCE AND TREATED AS THOUGH IT WERE DISTRIBUTED LINE IMPEDANCE--THIS ASSUMPTION SIMPLIFIES THE SOLUTION AT THE EXPENSE OF ACCURACY (SEE LOWER RIGHT HAND CORNER OF PAGE, ALSO TEXT).--THE SOLUTION BELOW IS BASED UPON THE VOLTAGE BEING HELD CONSTANT AT THE LOAD SIDE OF THE LOWERING TRANSFORMERS AND AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS.--IF THE VOLTAGE IS TO BE HELD CONSTANT AT THE GENERATOR BUS, THE IMPEDANCE OF THE RAISING TRANSFORMERS MUST ALSO BE ADDED TO THAT OF THE LINE--ALL LOW TENSION VALUES ARE REFERRED TO THE HIGH TENSION CIRCUIT.



EMERGENCY LOAD

PER 3 PHASE CIRCUIT	PER PHASE TO NEUTRAL
$KV\text{-}A_L = 176.470$	$KV\text{-}A_{LN} = 58.824$
$KW_L = 150{,}000$	$KW_{LN} = 50{,}000$
PF_L = 85% LAG.	PF_{LN} = 85% LAG.
$E_L = 220{,}000$	$E_{LN} = 127{,}020$
$I_L = 463.1$	$I_{LN} = 463.1$

60 CYCLES

CONDENSERS

FOUR 45,000 KV-A SYNCHRONOUS CONDENSERS PER 3 PHASE CIRCUIT WHEN OPERATING AT FULL LOAD PROVIDE MORE COMPENSATION THAN REQUIRED FOR MEETING THE EMERGENCY CONDITIONS—SINCE BOTH 3 PHASE CIRCUITS ON THE SAME TOWERS WILL BE OPERATED IN PARALLEL 7 CONDENSERS MAY BE USED FOR THE TWO CIRCUITS, THE 8TH CONDENSER BEING AVAILABLE AS A SPARE. UPON THIS BASIS THE CONDENSER DATA PER CIRCUIT IS AS FOLLOWS:

3 PHASE	TO NEUTRAL
$KV\text{-}A_C = 157{,}500$	$KV\text{-}A_{CN} = 52{,}500$
$E_C = 220{,}000$	$E_{CN} = 127{,}020$
$I_C = 413.34$	$I_{CN} = 413.34$
$KW_{C\text{-}LOSS} = 6300$	$KW_{C\text{-}LOSS\text{-}N} = 2100$
$I_{C\text{-}LOSS} = 16.53$	$I_{C\text{-}LOSS\text{-}N} = 16.53$

LINEAR CONSTANTS

$Z = 37.835 + j\,218.02$ OHMS ★
$Y = 0 + j\,.001211$ MHO

★ THIS INCLUDES IMPEDANCE OF LOWERING TRANSFORMERS

AUXILIARY CONSTANTS

$(A) = (a_1 + j\,a_2) = \cosh\theta = .870783 + j\,.021911$

$(B) = (b_1 + j\,b_2) = Z\dfrac{\sinh\theta}{\theta} = \sqrt{\dfrac{Z}{Y}}\sinh\theta = 34.5653 + j\,208.83$ OHMS

$(C) = (c_1 + j\,c_2) = Y\dfrac{\sinh\theta}{\theta} = \dfrac{1}{\sqrt{\dfrac{Z}{Y}}}\sinh\theta = -.000.009 + j\,.001158$ MHO.

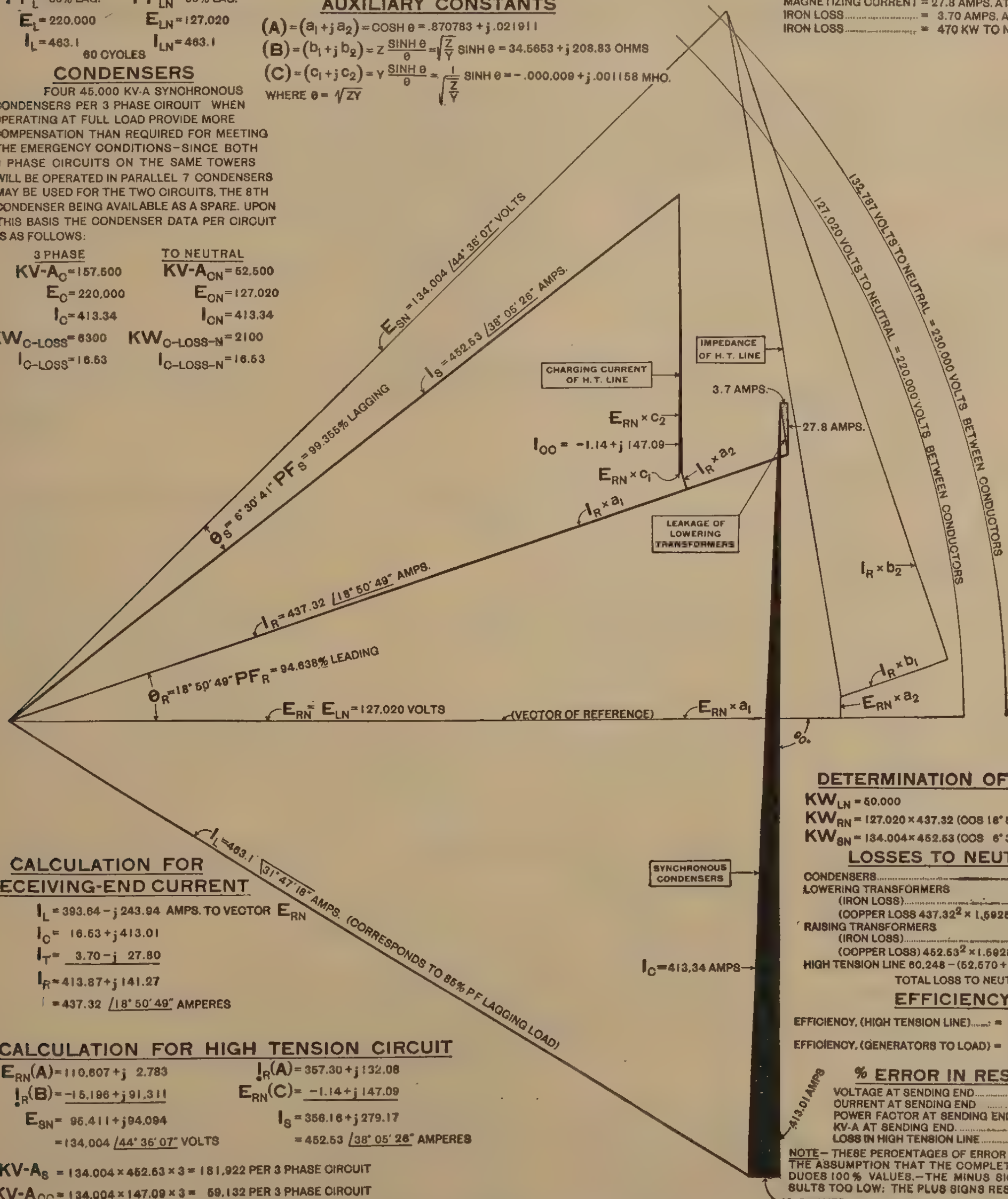
WHERE $\theta = \sqrt{ZY}$

TRANSFORMERS

(FOUR BANKS IN PARALLEL AT EACH END OF THE LINE)

R_{TN} = 1.5926 OHMS RESISTANCE
X_{TN} = 19.91 OHMS REACTANCE

MAGNETIZING CURRENT = 27.8 AMPS. AT 127,020 VOLTS
IRON LOSS .... = 3.70 AMPS. AT 127,020 VOLTS
IRON LOSS .... = 470 KW TO NEUTRAL



CALCULATION FOR RECEIVING-END CURRENT

$I_L = 393.64 - j\,243.94$ AMPS. TO VECTOR E_{RN}
$I_C = 16.53 + j\,413.01$
$I_T = \underline{3.70 - j\,27.80}$
$I_R = 413.87 + j\,141.27$
$= 437.32\ /18°\,50'\,49''$ AMPERES

CALCULATION FOR HIGH TENSION CIRCUIT

$E_{RN}(A) = 110.607 + j\,2.783$
$I_R(B) = \underline{-15.196 + j\,91.311}$
$E_{SN} = 95.411 + j\,94.094$
$= 134.004\ /44°\,36'\,07''$ VOLTS

$I_R(A) = 357.30 + j\,132.08$
$E_{RN}(C) = \underline{-1.14 + j\,147.09}$
$I_S = 356.16 + j\,279.17$
$= 452.53\ /38°\,05'\,26''$ AMPERES

$KV\text{-}A_S = 134.004 \times 452.53 \times 3 = 181{,}922$ PER 3 PHASE CIRCUIT
$KV\text{-}A_{CC} = 134.004 \times 147.09 \times 3 = 59{,}132$ PER 3 PHASE CIRCUIT

DETERMINATION OF LOSSES

$KW_{LN} = 50{,}000$
$KW_{RN} = 127.020 \times 437.32\ (\cos 18°\,50'\,49'') = 52{,}570$
$KW_{SN} = 134.004 \times 452.53\ (\cos 6°\,30'\,41'') = 60{,}248$

LOSSES TO NEUTRAL

CONDENSERS	= 2100
LOWERING TRANSFORMERS	
(IRON LOSS)	= 470
(COPPER LOSS $437.32^2 \times 1.5925$)	= 305
RAISING TRANSFORMERS	
(IRON LOSS)	= 470
(COPPER LOSS) $452.53^2 \times 1.5925$	= 326
HIGH TENSION LINE 60,248 − (52,570 + 305)	= 7373
TOTAL LOSS TO NEUTRAL	= 11,044

EFFICIENCY

EFFICIENCY, (HIGH TENSION LINE) ...... $= \dfrac{52{,}875}{60{,}248} = 87.76\%$

EFFICIENCY, (GENERATORS TO LOAD) $= \dfrac{50{,}000}{61{,}044} = 81.91\%$

% ERROR IN RESULTS

VOLTAGE AT SENDING END	= + 1.39 %
CURRENT AT SENDING END	= − 0.20 %
POWER FACTOR AT SENDING END	= − 0.56 %
KV-A AT SENDING END	= + 1.18 %
LOSS IN HIGH TENSION LINE	= + 5.33 %

NOTE—THESE PERCENTAGES OF ERROR ARE BASED UPON THE ASSUMPTION THAT THE COMPLETE METHOD PRODUCES 100 % VALUES.—THE MINUS SIGNS SIGNIFY RESULTS TOO LOW: THE PLUS SIGNS RESULTS TOO HIGH.

NOTE.—Linear constant *Z*, as used in this chart, incorrectly includes impedance of two banks, whereas it should have included four banks of transformers. This error will not, however, materially affect the result.

will be detected, since the point will not lie in the curve and an error in a curve corresponding to a given load will be detected by the curves of Fig. 72.

CAPACITY OF PHASE MODIFIERS

The curves of Fig. 70 show that, for a constant delivered load, power-factor and voltage, the leading

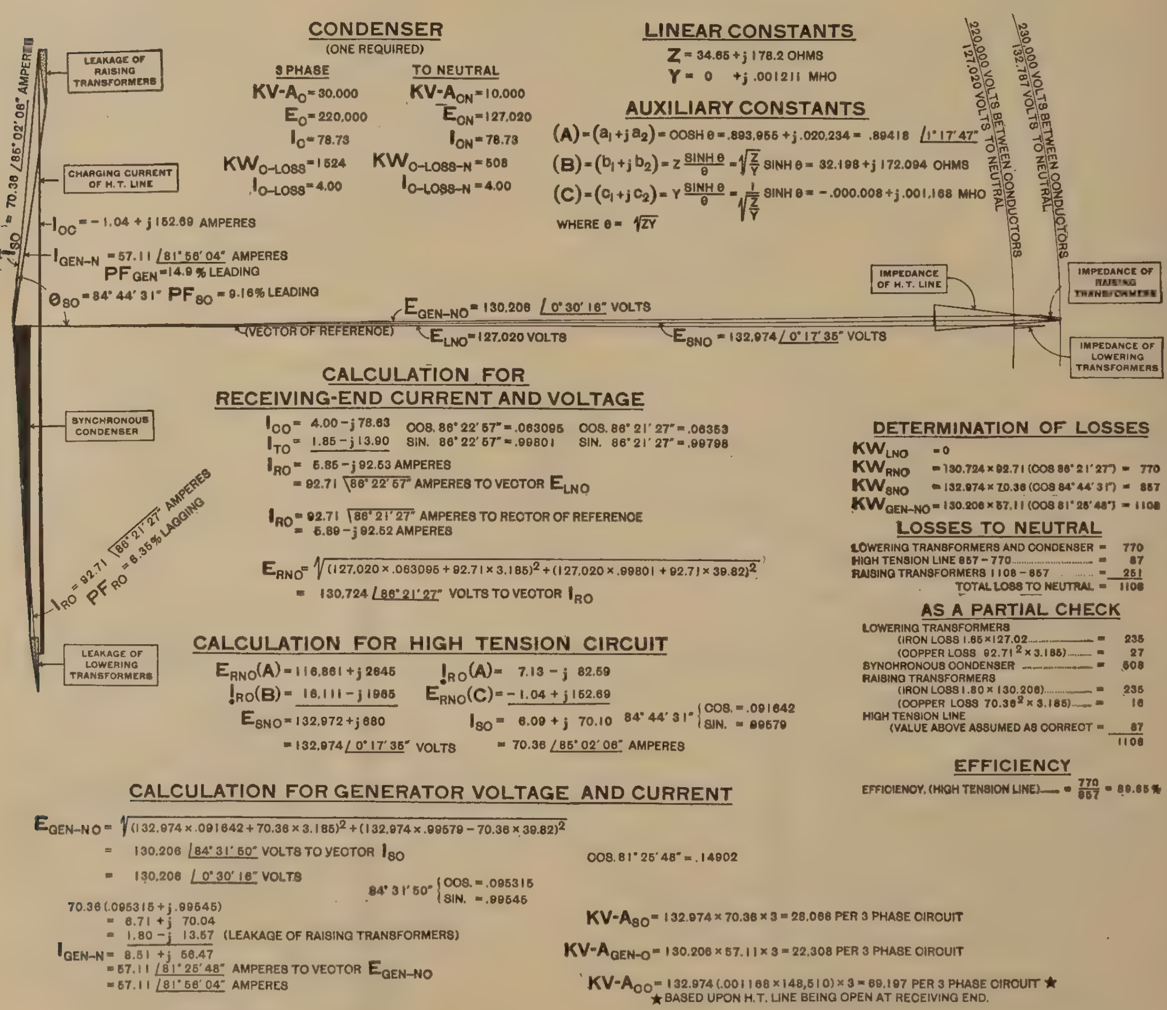
CHART XXVII—220 KV. PROBLEM—ZERO LOAD

(COMPLETE SOLUTION)

(THIS CORRESPONDS TO NORMAL LOAD CONNECTIONS)

AT ZERO LOAD, WITH 230,000 VOLTS MAINTAINED BETWEEN CONDUCTORS (132,787 VOLTS TO NEUTRAL), AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS THE VOLTAGE AT THE HIGH TENSION SIDE OF THE LOWERING TRANSFORMERS (NEGLECTING THE EFFECT OF THE LAGGING MAGNETIZING CURRENT OF THE LOWERING TRANSFORMERS) WILL RISE TO 230,000 DIVIDED BY (A)=230,000 DIVIDED BY .89418 = 257,219 VOLTS BETWEEN CONDUCTORS (148,510 VOLTS TO NEUTRAL). ACTUALLY THE GREATLY INCREASED LAGGING MAGNETIZING CURRENT OF THE LOWERING TRANSFORMERS WHEN EXCITED BY ABNORMALLY HIGH VOLTAGE WILL NOT PERMIT OF THE RECEIVING END VOLTAGE REACHING SUCH A HIGH VOLTAGE UNLESS THE GENERATOR VOLTAGE RAISES MOMENTARILY TO A VALUE GREATLY IN EXCESS OF 230,000 VOLTS. IF HOWEVER THE LOWERING TRANSFORMERS ARE DISCONNECTED FROM THE CIRCUIT, THE INCREASED LEADING CHARGING CURRENT OF THE LINE, REACTING UPON THE GENERATOR FIELDS, COMBINED WITH A MOMENTARY OVER SPEED OF THE GENERATORS MAY CAUSE THE RECEIVING END VOLTAGE TO GREATLY EXCEED THE ABOVE VALUE.

IN ORDER TO HOLD THE VOLTAGE AT THE RECEIVING END CONSTANT AT 220,000 VOLTS BETWEEN CONDUCTORS (127,020 VOLTS TO NEUTRAL) AT ZERO LOAD IT WILL BE NECESSARY TO PLACE AN ARTIFICIAL LAGGING LOAD AT THE LOAD END OF THE LINE--THIS IS ACCOMPLISHED BY OPERATING ONE OF THE SYNCHRONOUS CONDENSERS WITH ITS FIELDS UNDER EXCITED.--BY CONSTRUCTING SEVERAL VECTOR DIAGRAMS FOR THIS CIRCUIT EACH BASED UPON DIFFERENT VALUES OF REACTOR LOAD, A CURVE MAY BE DRAWN BY PLOTTING THE REACTOR LOADS AGAINST THE CORRESPONDING SENDING END VOLTAGES.--FROM THIS CURVE THE REACTOR CAPACITY CORRESPONDING TO 230,000 VOLTS BETWEEN CONDUCTORS AT THE SENDING END WILL BE SEEN TO BE APPROXIMATELY 30,000 KV-A



capacity of phase modifiers required goes down as the line drop increases. For instance 75,000 kw. at 85 per cent power-factor and 220 kv. can be delivered over this line with 230 kv. sending-end voltage, if 43,000 kv.a. condenser capacity is placed in parallel with the load. If, however, a line drop of 20 kv. is selected in place of 10 kv. the sending-end voltage will be 240 kv. and the corresponding condenser load will be reduced to approximately 30,000 kv.a. On the other hand this increased line drop will necessitate a greater capacity at zero load in order to maintain 240 kw. constant at the sending end. Thus with 230 kv. at the sending end, about 30,000 kv.a. reactor load will be required at zero load, whereas with 240 kv. at the sending end, about 40,000 kv.a. reactor load will be required at zero load.

Obviously the smallest phase modifier capacity possible to maintain regulation is one in which full capacity leading will be required under maximum load and full capacity lagging under zero load. At half load

such a phase modifier would operate at near zero kv.a. The dotted line in Fig. 70 is simply the zero load line thrown over to the leading load side to facilitate study in phase modifier capacity. For instance, projection from the points where the dotted line intersects a load curve will give the minimum capacity of phase modifier on the bottom scale and the corresponding sending-end voltage on the vertical scale to the left. Thus with a load of 75,000 kw., intersection of the dotted line with this load curve indicates that 33,000 kv.a. phase modi-standard condensers usually cannot be operated at lagging loads above approximately 70 per cent of their full load leading rating. To deliver 75,000 kv.a. at 85 per cent power-factor requires approximately 42,000 kv.a. in phase modifier capacity with 230 kv. at the sending end. To maintain the sending-end voltage of 230 kv. at zero load requires approximately 30,000 kv.a. lagging. This is 70 per cent of the capacity leading, thus permitting of employing a standard 43,000 kv.a. condenser. To provide margin a 45,000 kv.a. standard

CHART XXVIII—220 KV. PROBLEM—ZERO LOAD

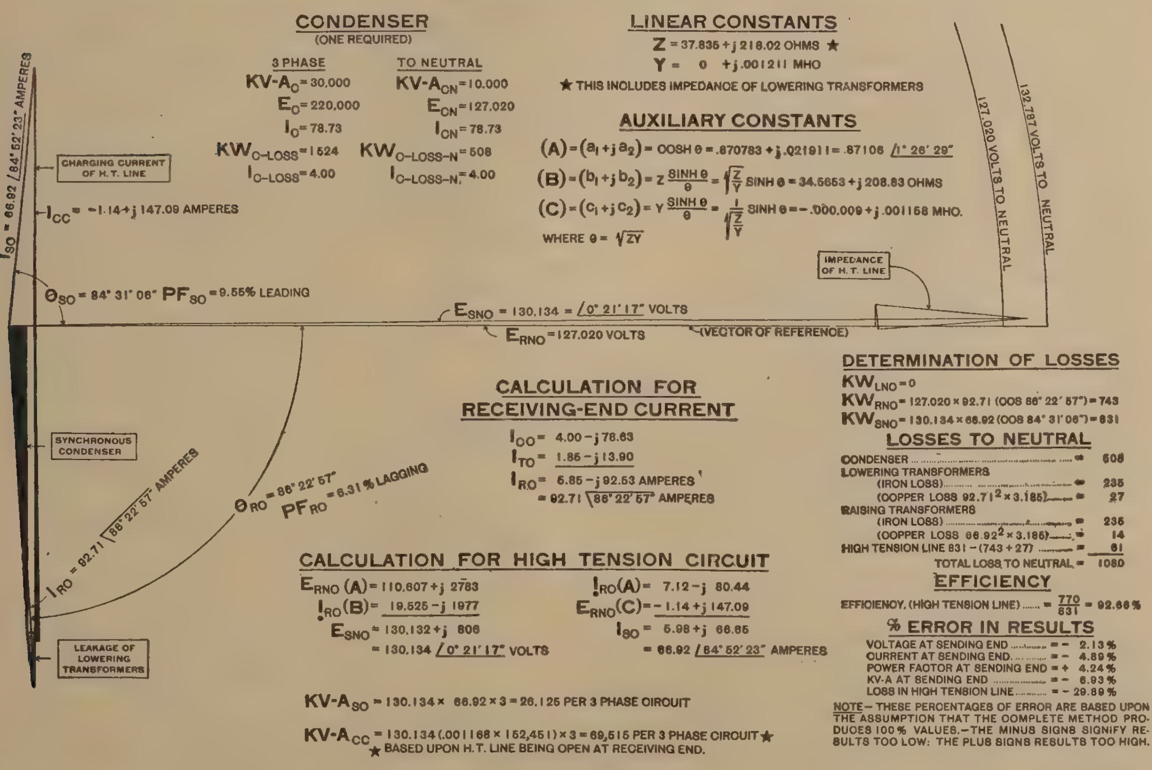
(APPROXIMATE SOLUTION)

(THIS CORRESPONDS TO THE NORMAL LOAD CONNECTIONS)

THIS APPROXIMATE SOLUTION ASSUMES THAT THE IMPEDANCE OF THE LOWERING TRANSFORMERS MAY BE ADDED TO THE LINE IMPEDANCE AND TREATED AS THOUGH IT WERE DISTRIBUTED LINE IMPEDANCE--THIS ASSUMPTION SIMPLIFIES THE SOLUTION AT THE EXPENSE OF ACCURACY (SEE LOWER RIGHT HAND CORNER OF PAGE; ALSO TEXT).--THE SOLUTION BELOW IS BASED UPON THE VOLTAGE BEING HELD CONSTANT AT THE LOAD SIDE OF THE LOWERING TRANSFORMERS AND AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS.--IF THE VOLTAGE IS TO BE HELD CONSTANT AT THE GENERATOR BUS, THE IMPEDANCE OF THE RAISING TRANSFORMERS MUST ALSO BE ADDED TO THAT OF THE LINE--ALL LOW TENSION VALUES ARE REFERRED TO THE HIGH TENSION CIRCUIT.

AT ZERO LOAD, WITH 230,000 VOLTS MAINTAINED BETWEEN CONDUCTORS (132,787 VOLTS TO NEUTRAL), AT THE HIGH TENSION SIDE OF THE RAISING TRANSFORMERS THE VOLTAGE AT THE HIGH TENSION SIDE OF THE LOWERING TRANSFORMERS (NEGLECTING THE EFFECT OF THE LAGGING MAGNETIZING CURRENT OF THE LOWERING TRANSFORMERS) WILL RISE TO 230,000 DIVIDED BY (A) = 230,000 DIVIDED BY 87106 = 264,046 VOLTS BETWEEN CONDUCTORS 152 451VOLTS TO NEUTRAL). ACTUALLY THE GREATLY INCREASED LAGGING MAGNETIZING CURRENT OF THE LOWERING TRANSFORMERS WHEN EXCITED BY ABNORMALLY HIGH VOLTAGE WILL NOT PERMIT OF THE RECEIVING END VOLTAGE REACHING SUCH A HIGH VOLTAGE UNLESS THE GENERATOR VOLTAGE RAISES MOMENTARILY TO A VALUE GREATLY IN EXCESS OF 230,000 VOLTS. IF HOWEVER THE LOWERING TRANSFORMERS ARE DISCONNECTED FROM THE CIRCUIT, THE INCREASED LEADING CHARGING CURRENT OF THE LINE, REACTING UPON THE GENERATOR FIELDS, COMBINED WITH A MOMENTARY OVER SPEED OF THE GENERATORS MAY CAUSE THE RECEIVING END VOLTAGE TO GREATLY EXCEED THE ABOVE VALUE.

IN ORDER TO HOLD THE VOLTAGE AT THE RECEIVING END CONSTANT AT 220,000 VOLTS BETWEEN CONDUCTORS (127,020 VOLTS TO NEUTRAL) AT ZERO LOAD IT WILL BE NECESSARY TO PLACE AN ARTIFICIAL LAGGING LOAD AT THE LOAD END OF THE LINE--THIS IS ACCOMPLISHED BY OPERATING ONE OF THE SYNCHRONOUS CONDENSERS WITH ITS FIELDS UNDER EXCITED.--BY CONSTRUCTING SEVERAL VECTOR DIAGRAMS FOR THIS CIRCUIT EACH BASED UPON DIFFERENT VALUES OF REACTOR LOAD, A CURVE MAY BE DRAWN BY PLOTTING THE REACTOR LOADS AGAINST THE CORRESPONDING SENDING END VOLTAGES.--FROM THIS CURVE THE REACTOR CAPACITY CORRESPONDING TO 230,000 VOLTS BETWEEN CONDUCTORS AT THE SENDING END WILL BE SEEN TO BE APPROXIMATELY 30,000 KV-A



fier capacity will be required both at this load and at zero load and that the corresponding sending-end voltage will be approximately 236 kv. At 100,000 kw. load, nearly 50,000 kv.a. phase modifier capacity will be required, and the corresponding sending-end voltage would be 250 kv.

As previously stated, phase modifiers which may be operated at rated load both lagging and leading are special, and cost more than standard phase modifiers. On account of unstable operation due to weakened field, condenser might be selected for this normal load condition.

Under emergency conditions (that is, double or 150,000 kw. load at 85 per cent power-factor) 157,000 kv.a. phase modifier capacity will be required if 230 kv. is not to be exceeded at the sending end. If the generator can be operated during the emergency condition at increased voltage of, for instance, 240 kv. the phase modifier capacity could be reduced to approximately 140,000 kv.a. However, too much

liberty in variation of generator operating voltage should not be taken. If the voltage is held constant at the high-voltage side of the raising transformers, the generator operating voltage will have to be varied to compensate for the regulation of the sending-end trans-

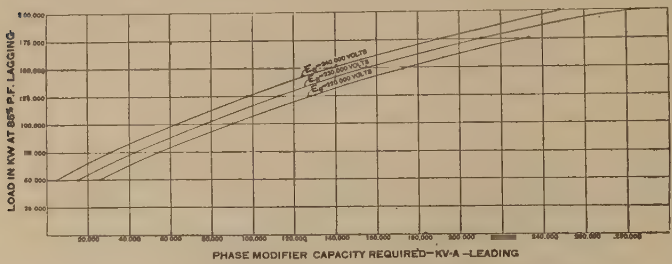


Fig. 72.—Phase modifier capacity required for the various loads.
These curves are plotted from values read from the curves of Fig. 70 and are on the basis of a constant load voltage of 220 kv.

formers. Morever, and to provide a still greater range in generator operating voltage might impose a hardship on the generator designers. The voltage drop through the transformers is small under load conditions, since the power-factor will be near unity; but under zero load condition the drop will be considerable, due to the low power-factor, especially if a large phase modifier load is required at zero load. It will be seen that it is the emergency condition which determines the total capacity of phase modifiers, for the 220-kv. problem. For instance at normal load, 43,000 kv.a. in capacity is required, whereas for the double or emergency load 157,000 kv.a. capacity (nearly four times) is required. This large increase is due to the fact that the line charging current (which tends to reduce phase modifier capacity under load) has not changed, and that the line impedance volts has become twice as much, making it necessary to turn the line impedance triangle through a large angle in the counter-clockwise direction in order that the sending-end voltage be not increased.

The zero load curve on Fig. 70 is drawn for the normal load connection; that is, for two 50,000 kv.a. transformer banks in parallel. For the emergency load four transformer banks in parallel will be required. The result of the increased magnetizing current consumed by four in place of two transformer banks will be to reduce the capacity of phase modifiers required under zero load. A second zero load line could be added, covering four transformer banks. Such a line would be directly above the one for two transformer banks but would not materially affect the results. For load conditions of 100,000 kw. at 85 per cent power factor and above, the points for the curves were determined on the basis of four transformer banks.

In the above it was assumed that the power-factor of the load would be 85 per cent lagging. A long line such as this would probably feed into an extended distribution net work, having numerous load centers. At these load centers synchronous condensers would probably be located for the purpose of holding the voltage constant. This would necessitate operating the condenser leading at

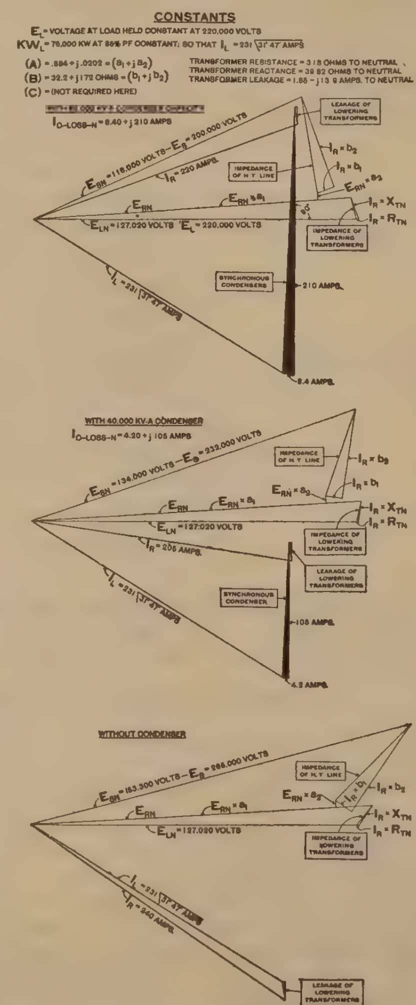


Fig. 71.—Graphic method for determining the voltage at the sending end.
Corresponding to different condenser loads in parallel with a constant power load of 75,000 kw. at 85 per cent power-factor and 220 kv. The results as plotted in Fig. 70 were obtained by similar constructions.

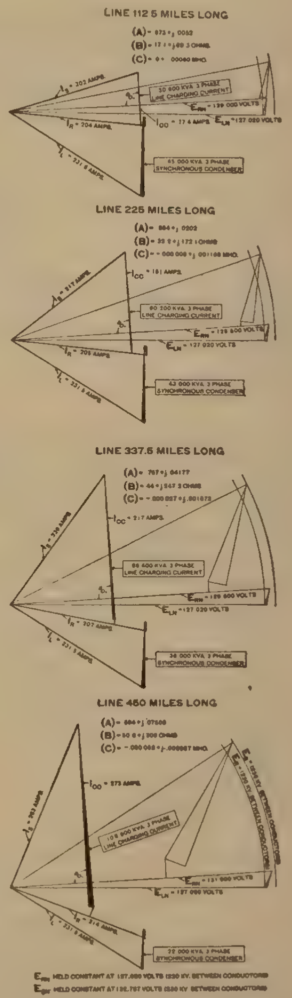


Fig. 73.—Vector diagrams showing the effect of the length of the line on the phase modifier capacity required.

The diagrams represent a three-phase, 60-cycle circuit, consisting of three 605,000 circ. mil aluminum steel reinforced conductors, when delivering 75,000 kw. at 85 per cent lagging power-factor at a load voltage of 220 kv. with a sending end voltage of 230 kv.

heavy loads thus raising the power-factor of the entire system under load, and in effect reducing the capacity of phase modifiers required for voltage control at the receiving end of the line. This point should be investigated where a long line such as this feeds a net work on which condensers are required for voltage control.

It may be desired to investigate the effect of line charging current on phase modifier capacity for lines of different lengths. For this purpose the vector diagrams Fig. 73, and the phase modifier curves, Fig. 74, were prepared. These vector diagrams and curves are based upon a constant load of 75,000 kw. at 85 per cent

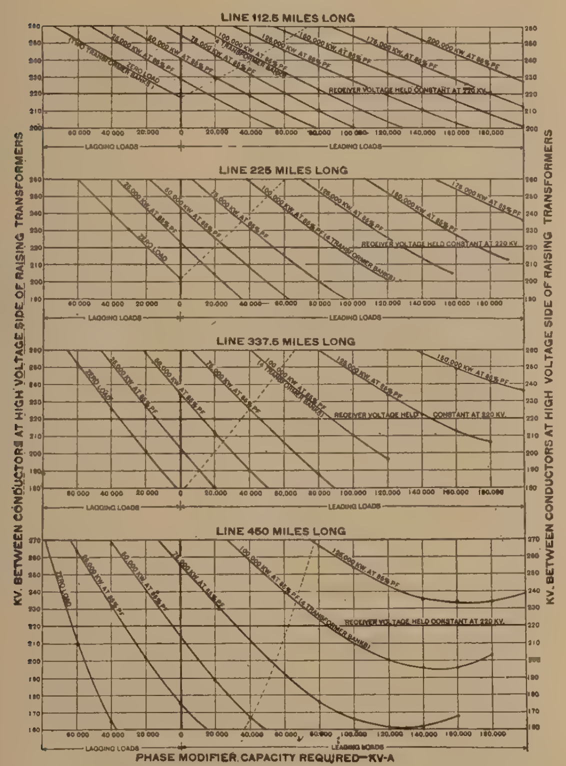


FIG. 74.—Curve showing the relation between phase modifier capacity and sending end voltage.

For various receiving-end loads of 85 per cent lagging power-factor and a constant load voltage of 220 kv. These curves apply to a three-phase, 60-cycle circuit consisting of three 605,000 circ. mil aluminum steel conductors. The vector construction of these four lines is shown in Fig. 73.

power-factor delivered at 220 kv. and a line drop of 10 kv. In other words the only variable for the four different lines is the length and this varies in equal increments.

The vector diagrams of Fig. 73 show the influence of line charging current upon condenser capacity. As the length of the line increases, the influence of the increased line charging current is toward a reduction in condenser capacity; that is the line itself furnishes a large part of the leading current necesary to maintain the proper line voltage drop. If this line were longer than 450 miles, the line charging current at a certain length would be sufficient in itself to maintain the desired voltages at the two ends of the line without the aid of condensers. In such a case, however, a large reactor capacity would be required at zero and low loads to hold the receiving end voltage at a constant value.

The reason that a short line may necessitate more condenser capacities for voltage control than a long line is simple. For the 112.5 mile line the charging current will be about one-half as much as for a 225 mile line. Since the line is only half as long this small charging current will flow through only half the inductance so that the net result of half the line charging current and half the inductance will be about one-fourth the voltage boosting effect due to line charging current. On the other hand the line impedance will be only half as great, but the net result will be more condenser capacity for the short line. A large part of the condenser capacity is required for neutralizing the lagging reactive component of the load.

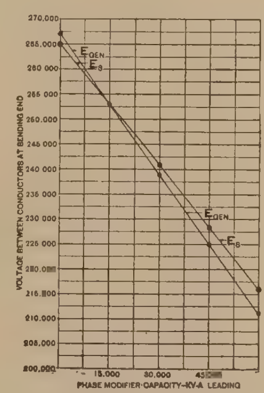


FIG. 75.—Curves showing the voltage on each side of the raising transformers.

Corresponding to condenser loads of various capacities in parallel with a constant load of 75,000 kw. at 85 per cent power factor lagging and 220 kv. The vertical distance between the two voltage lines is the voltage drop or voltage rise through the raising transformers. For condenser loads up to 15,000 kv.a. there is a drop in voltage through the raising transformers. For condenser loads above 15,000 kv.a. there is a rise in voltage through the raising transformers.

Auxiliary constant A, as previously explained, accounts for the effects of the line charging current flowing through the impedance of the circuit; that is, the voltage boosting effect of the charging current. Thus for the 112.5-mile line (Fig. 73) a_1 which accounts for the line charging current flowing through the inductance of the circuit is near unity and a_2 near zero, but for the 450-mile line a_1 drops to 0.594 and a_2 ncreases to 0.07508. As the length of line increases, constant A moves the line impedance triangle to the left and raises its toe somewhat. The increased line impedance and slightly increased current at the receiving end increases the size of the line impedance triangle.

The curves of Fig. 74 show the relation between phase modifier capacity and sending-end voltage for different receiving-end loads of 85 per cent lagging power-factor and a constant load voltage of 220 kv. It is interesting to note the effect of distance for fixed

size conductors upon the maximum amount of power which can be transmitted over a circuit, as evidenced by the load curves bending upward as the line length increases. It is also interesting to note the decrease in phase modifiers leading capacity and increase in phase modifier lagging capacity as the line becomes larger, as evidenced by the load curves shifting to the right. The curves, Fig. 75, show the voltage at each side of the raising transformer, corresponding to various condenser capacities in parallel with a constant load of 75,000 kw. at 85 per cent lagging power-factor and 220 kv.

CHAPTER XV

GENERAL CIRCUIT CONSTANTS AND CIRCLE DIAGRAMS

In calculating the performance of a high voltage transmission system, the method usually followed is to determine, first, the voltage and current conditions at the receiving and sending ends of the transmission line itself. When raising or lowering transformers are used, as is always the case with long high voltage lines, their effect is calculated separately and added to the line effect in order to determine the over-all performance of the system. This method, known as the "step-by-step" method, is the one which has been followed in the preceding chapters. By this method, a separate complete solution is required for every change in voltage or load conditions.

The circle diagram as a valuable aid in analyzing the performance of transmission lines was first described by R. A. Philip.* His method is restricted in application to short lines in which capacity can be neglected and in which the voltage is held not only *constant* but *equal* at both ends of the line. Later H. B. Dwight† extended the application of the circle diagram to include the effect of distributed admittance, thus extending its use to the general case of any smooth line. Other variations of the circle diagram have been published by P. H. Thomas‡ and L. F. Woodruff.§

The general presentation of the general circuit constants and of the circle diagram which follows, is based primarily on the work of Messrs. R. D. Evans and H. K. Sels,|| who have extended this method to include not only the power circle diagram, but also the loss circle and efficiency circle diagrams, thus enabling a complete analysis of power, losses and efficiencies to be made for any system by this convenient graphical method. A useful modification of the Evans and Sels diagram by C. L. Fortescue,¶ which introduces the idea of the phase angle between the terminal voltages, is incorporated in the following treatment, as well as a modification of the loss diagram by C. F. Wagner, also based on the angle idea. The treatment has also been extended to include the current circle diagram, as developed by Mr. Fortescue.

Along with the circle diagram, Messrs. Evans and Sels have worked out so called "general circuit" constants for many types of network, by means of which the circle diagram can be used to analyze not only the performance of the line itself, but also the over-all performance of a complete transmission system or network from the low tension bus of the generator to that of the load. A paper on "The Calculation of Transmission Line Networks"** by Prof. T. R. Rosebrugh of Toronto University gives a very complete and general analysis for networks and is a valuable reference in this connection.

Since the most general application of the circle diagram involves the use of general circuit constants, these will be discussed first.

GENERAL CIRCUIT CONSTANTS

The following equations showing the relation between the sending and receiving end voltages and currents of a transmission line have been given previously,

$$E_s = E_rA + I_rB \tag{1}$$
$$I_s = I_rA + E_rC \tag{2}$$
$$E_r = E_sA - I_sB \tag{3}$$
$$I_r = I_sA - E_sC \tag{4}$$

where A, B and C are the auxiliary or circuit constants for the line alone, the line being assumed as symmetrical about its middle point.

When the transmission line is not symmetrical, as, for instance, in the case of a composite line having two or more sections with different characteristics, a fourth constant, D is required to provide for the general case and the above equations would be written:

$$E_s = E_rA + I_rB \tag{5}$$
$$I_s = I_rD + E_rC \tag{6}$$
$$E_r = E_sD - I_sB \tag{7}$$
$$I_r = I_sA - E_sC \tag{8}$$

The difference is simply that the constant D is substituted for constant A in equations 2 and 3, the inequality between A and D existing only when the line is unsymmetrical.

Equations (5) to (8) are general equations which, as shown below, may be applied to any circuit or network from a simple impedance or shunt admittance to any combination of impedances and admittances in series or parallel, by assigning the proper values to the constants A, B, C and D. The "General Circuit" constants may, therefore, be defined as those which satisfy equations (5) to (8) for any elementary or general network as a whole.

Since the "auxiliary" constants for the line only and the "general circuit" constants for a network are used in the same way to express the relation between voltage and current at the two ends of a circuit, the

* Transactions A. I. E. E., Vol. XXX, 1911, pp. 596–636.

† Electric Journal, August, 1914, Vol. XI, p. 487.

‡ Electrical World, October 31st, 1925.

§ Electrical World, September 6th, 1924.

|| Electric Journal, July, August and December, 1921 and February 1922.

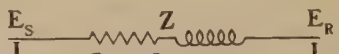
¶ Transactions, A. I. E. E., Vol. XLIII, February, 1924.

** Bulletin No. 1, 1919, School of Engineering Research, University of Toronto.

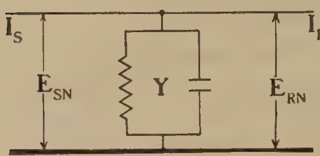
same symbols A, B and C, may be used logically in both cases, with the addition of D, to cover the general case, as mentioned above. This is done in the following text, the constants being referred to as "general circuit" constants when they apply to composite lines or networks.

The applicability of general circuit constants as stated above, will be clear from the following considerations:

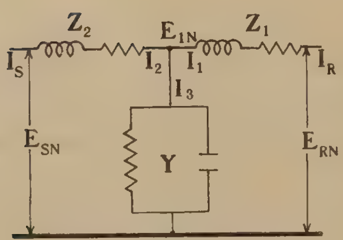
The constants for a series impedance, Z, and a shunt admittance, Y, in accordance with the definition above, are derived as follows:



SERIES IMPEDANCE



SHUNT ADMITTANCE



IMPEDANCE AND ADMITTANCE

Referring to the diagram, it is evident that for a series impedance

$$E_s = E_r + I_rZ$$
$$I_s = I_r$$

from which,

$$A = 1$$
$$B = Z$$
$$C = O$$
$$D = 1$$

Similarly, for a shunt admittance, as indicated

$$E_{sn} = E_{rn}$$
$$I_s = I_r + E_{rn}Y$$

from which

$$A = 1$$
$$B = 0$$
$$C = Y$$
$$D = 1$$

For an impedance Z, shunted by an admittance Y, at any point dividing Z into parts Z_1 and Z_2, we have

$$E_{1n} = E_{rn} + I_rZ_1$$
$$I_1 = I_r$$
$$I_3 = E_{1n}Y = (E_{rn} + I_r Z_1)Y$$
$$I_2 = I_1 + I_3 = I_r(1 + Z_1Y) + E_{rn}Y$$
$$E_{sn} = E_{1n} + I_2Z_2$$
$$= E_{rn}(1 + Z_2Y) + I_r(Z_1 + Z_2 + Z_1Z_2Y)$$
$$I_s = I_2 = I_r(1 + Z_1Y) + E_{rn}Y$$

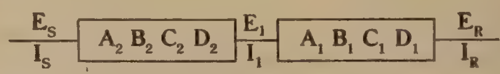
from which

$$A = 1 + Z_2Y$$
$$B = Z_1 + Z_2 + Z_1Z_2Y$$
$$C = Y$$
$$D = 1 + Z_1Y$$

The network as shown represents the familiar equivalent circuit for a transformer with the series impedances representing the leakage reactance of the transformer and Y representing the exciting admittance. It is customary to assume $Z_1 = Z_2 = Z/2$ and for this combination the constants become

$$A = 1 + \frac{ZY}{2}$$
$$B = Z\left(1 + \frac{ZY}{4}\right)$$
$$C = Y$$
$$D = 1 + \frac{ZY}{2}$$

Two of these elementary networks may be combined in series, having constants, voltages and currents as indicated below:



Then from equations (5) and (6)

$$E_1 = E_rA_1 + I_rB_1 \tag{9}$$
$$I_1 = I_rD_1 + E_rC_1 \tag{10}$$
$$E_s = E_1A_2 + I_1B_2 \tag{11}$$
$$I_s = I_1D_2 + E_1C_2 \tag{12}$$

Substituting in (11) and (12) the values of E_1 and I_1 in (9) and (10) we get

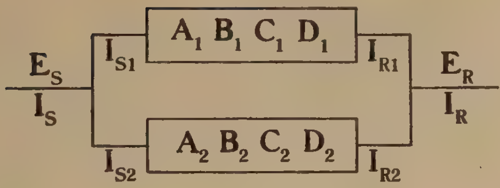
$$E_s = (E_rA_1 + I_rB_1)A_2 + (I_rD_1 + E_rC_1)B_2$$
$$= E_r(A_1A_2 + C_1B_2) + I_r(B_1A_2 + D_1B_2) \tag{13}$$
$$I_s = (I_rD_1 + E_rC_1)D_2 + (E_rA_1 + I_rB_1)C_2$$
$$= I_r(B_1C_2 + D_1D_2) + E_r(A_1C_2 + C_1D_2) \tag{14}$$

Equations (13) and (14) are in the form of equations (5) and (6) and the general circuit constants for two networks in series may be written:

$$A = A_1A_2 + C_1B_2 \tag{15}$$
$$B = B_1A_2 + D_1B_2 \tag{16}$$
$$C = A_1C_2 + C_1D_2 \tag{17}$$
$$D = B_1C_2 + D_1D_2 \tag{18}$$

Constants A, B, C and D may be combined in turn with a third network in series, and by continuing the process, an indefinite number of networks may be added in series. It will be noted also that equations (15) to (18) cover the series combination of two general networks and the process may thus be extended to cover all cases. Hence, the use of A, B, C and D constants is applicable to all networks made up of elementary networks in series.

In a similar manner, two elementary networks may be combined in parallel, the constants, voltages and currents being as indicated below:



Then from equations (5) and (6)

$$E_s = E_rA_1 + I_{r1}B_1 = E_rA_2 + I_{r2}B_2 \quad (19)$$
$$I_{s1} = I_{r1}D_1 + E_rC_1 \quad (20)$$
$$I_{s2} = I_{r2}D_2 + E_rC_2 \quad (21)$$
$$I_r = I_{r1} + I_{r2} \quad (22)$$
$$I_s = I_{s1} + I_{s2} \quad (23)$$

From (22) and (23)

$$I_{r1} = I_r - I_{r2} \quad (24)$$
$$I_{r2} = I_r - I_{r1} \quad (25)$$
$$I_{s1} = I_s - I_{s2} \quad (26)$$
$$I_{s2} = I_s - I_{s1} \quad (27)$$

From (19)

$$I_{r1}B_1 = E_r(A_2 - A_1) + I_{r2}B_2 \quad (28)$$
$$I_{r2}B_2 = E_r(A_1 - A_2) + I_{r1}B_1 \quad (29)$$

Substituting for I_{r2} in (28)

$$I_{r1}B_1 = E_r(A_2 - A_1) + (I_r - I_{r1})B_2$$
$$I_{1r}(B_1 + B_2) = E_r(A_2 - A_1) + I_rB_2$$
$$I_{r1} = \frac{E_r(A_2 - A_1) + I_rB_2}{B_1 + B_2} \quad (30)$$

Substituting for I_{r1} in (28)

$$(I_r - I_{r2})B_1 = E_r(A_2 - A_1) + I_{r2}B_2$$
$$I_{r2}(B_1 + B_2) = E_r(A_1 - A_2) + I_rB_1$$
$$I_{r2} = \frac{E_r(A_1 - A_2) + I_rB_1}{B_1 + B_2} \quad (31)$$

Substituting in (19) the value of I_{r1} in (30) we get the voltage equation—

$$E_s = E_rA_1 + \frac{E_r(A_2 - A_1) + I_rB_2}{B_1 + B_2} \times B_1$$
$$= \frac{E_r(A_1B_1 + A_1B_2 + A_2B_1 - A_1B_1) + I_rB_1B_2}{B_1 + B_2}$$
$$= E_r\left(\frac{A_1B_2 + A_2B_1}{B_1 + B_2}\right) + I_r\left(\frac{B_1B_2}{B_1 + B_2}\right) \quad (32)$$

The same value would be obtained by substituting in (19) the value of I_{r2} in (31).

Substituting in equations (20) and (21) the values of I_{r1} and I_{r2} in (30) and (31) we get the current equations

$$I_{s1} = \frac{E_r(A_2 - A_1) + I_rB_2}{B_1 + B_2} \times D_1 + E_rC_1 \quad (33)$$
$$I_{s2} = \frac{E_r(A_1 - A_2) + I_rB_1}{B_1 + B_2} \times D_2 + E_rC_2 \quad (34)$$

Substituting in (23) the values of I_{s1} and I_{s2} in (33) and (34) we have—

$$I_s = \frac{E_r(A_2 - A_1) + I_rB_2}{B_1 + B_2} \times D_1 + E_rC_1 + \frac{E_r(A_1 - A_2) + I_rB_1}{B_1 + B_2} \times D_2 + E_rC_2$$
$$= I_r\left(\frac{B_2D_1 + B_1D_2}{B_1 + B_2}\right) + E_r\left(C_1 + C_2 + \frac{A_2D_1 - A_1D_1 + A_1D_2 - A_2D_2}{B_1 + B_2}\right)$$
$$= I_r\left(\frac{B_2D_1 + B_1D_2}{B_1 + B_2}\right) + E_r\left\{C_1 + C_2 + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}\right\} \quad (35)$$

Equations (32) and (35) are in the form of equations (5) and (6) and we have as the general circuit constants for two elementary networks in parallel

$$A = \frac{A_1B_2 + B_1A_2}{B_1 + B_2} \quad (36)$$
$$B = \frac{B_1B_2}{B_1 + B_2} \quad (37)$$
$$C = C_1 + C_2 + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2} \quad (38)$$
$$D = \frac{B_1D_2 + D_1B_2}{B_1 + B_2} \quad (39)$$

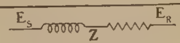
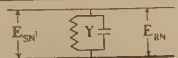
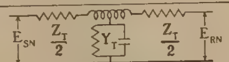
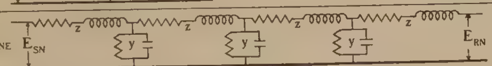
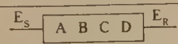
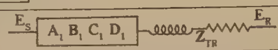
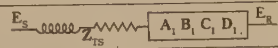
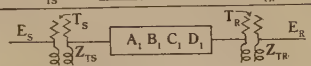
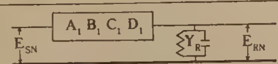
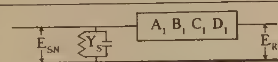
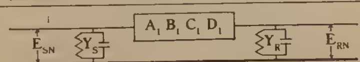
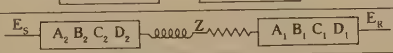
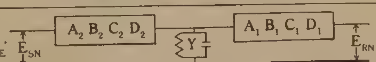
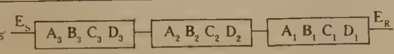
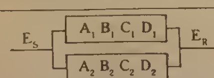
As with series networks, the process may be extended to cover any number of networks in parallel, and parallel and series networks may be combined also. By the combination of series impedances and shunt admittances any network may be formed. Hence, the applicability of A, B, C and D constants to any network is demonstrated. The equations for the general circuit constants for the more important cases of elementary and general networks are given in the table on the next page.

The Table of General Circuit Constants

The expressions for the general circuit constants, as given in the table are exact, individually and in combination, for the various types of networks represented. The accuracy of their application depends only on the degree to which the elements assumed as making up the general network in a particular case correctly represent all of the conditions entering into the problem. The problem of including the effect of transformers in the line constants has resulted in the use of various approximate methods. One method which has been used, is to add the series impedance of the transformers to the line impedance, and the shunt admittance of the transformers to the line admittance, the values of Z and Y so obtained being used to determine by the hyperbolic method or convergent series, the equivalent auxiliary or circuit constants of the transmission system. This method is not to be recommended, as it does not have a rational basis and is not a convenient one to employ. Another approximate method is to add the series impedance of the transformer to the B constant of the line to obtain the B constant, and to add the shunt admittance of the transformer to the C constant of the line, to obtain the C constant. This method is quite approximate and is not to be recommended on account of its inaccuracy.

Reference to the table will show that for problems involving transmission lines and transformers, two general methods of solution may be employed. A transformer may be accurately represented by Network No. 3, in which Z_t represents the impedance and Y_t represents the shunt admittance of the transformer. In this network, the exciting admittance of the transformer is included as a constant of the transmission

GENERAL CIRCUIT CONSTANTS FOR DIFFERENT TYPES OF NETWORKS

NETWORK NUMBER	TYPE OF NETWORK		EQUATIONS FOR GENERAL CIRCUIT CONSTANTS IN TERMS OF CONSTANTS OF COMPONENT NETWORKS			
			A=	B=	C=	D=
1	Series Impedance		1	Z	0	1
2	Shunt Admittance		1	0	Y	1
3	Transformer		$1+\frac{Z_TY_T}{2}$	$Z_T\left(1+\frac{Z_TY_T}{4}\right)$	Y_T	$1+\frac{Z_TY_T}{2}$
4	Transmission Line		$\text{Cosh}\sqrt{ZY} = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\cdots\right)$	$\sqrt{Z/Y}\,\text{Sinh}\sqrt{ZY} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\cdots\right)$	$\sqrt{Y/Z}\,\text{Sinh}\sqrt{ZY} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\cdots\right)$	Same As A
5	General Network		A	B	C	D
6	General Network and Transformer Impedance at Receiving End		A_1	$B_1+A_1Z_{TR}$	C_1	$D_1+C_1Z_{TR}$
7	General Network and Transformer Impedance at Sending End		$A_1+C_1Z_{TS}$	$B_1+D_1Z_{TS}$	C_1	D_1
8	General Network and Transformer Impedance at Both Ends—Referred to High Voltage		$A_1+C_1Z_{TS}$	$B_1+A_1Z_{TR}+D_1Z_{TS}+C_1Z_{TR}Z_{TS}$	C_1	$D_1+C_1Z_{TR}$
9	General Network and Transformer Impedance at Both Ends–Transformers Having Different Ratios. T_R and T_S Referred to Low Voltage		$\frac{T_R}{T_S}\left(A_1+C_1Z_{TS}\right)$	$\frac{1}{T_RT_S}\left(B_1+A_1Z_{TR}+D_1Z_{TS}+C_1Z_{TR}Z_{TS}\right)$	$C_1T_RT_S$	$\frac{T_S}{T_R}\left(D_1+C_1Z_{TR}\right)$
10	General Network and Shunt Admittance at Receiving End		$A_1+B_1Y_R$	B_1	$C_1+D_1Y_R$	D_1
11	General Network and Shunt Admittance at Sending End		A_1	B_1	$C_1+A_1Y_S$	$D_1+B_1Y_S$
12	General Network and Shunt Admittance at Both Ends		$A_1+B_1Y_R$	B_1	$C_1+A_1Y_S+D_1Y_R+B_1Y_RY_S$	$D_1+B_1Y_S$
13	Two General Networks in Series.		$A_1A_2+C_1B_2$	$B_1A_2+D_1B_2$	$A_1C_2+C_1D_2$	$B_1C_2+D_1D_2$
14	Two General Networks in Series. With Intermediate Impedance		$A_1A_2+C_1B_2+C_1A_2Z$	$B_1A_2+D_1B_2+D_1A_2Z$	$A_1C_2+C_1D_2+C_1C_2Z$	$B_1C_2+D_1D_2+D_1C_2Z$
15	Two General Networks in Series. With Intermediate Shunt Admittance		$A_1A_2+C_1B_2+A_1B_2Y$	$B_1A_2+D_1B_2+B_1B_2Y$	$A_1C_2+C_1D_2+A_1D_2Y$	$B_1C_2+D_1D_2+B_1D_2Y$
16	Three General Networks in Series		$A_3\left(A_1A_2+C_1B_2\right)+B_3\left(A_1C_2+C_1D_2\right)$	$A_3\left(B_1A_2+D_1B_2\right)+B_3\left(B_1C_2+D_1D_2\right)$	$C_3\left(A_1A_2+C_1B_2\right)+D_3\left(A_1C_2+C_1D_2\right)$	$C_3\left(B_1A_2+D_1B_2\right)+D_3\left(B_1C_2+D_1D_2\right)$
17	Two General Networks in Parallel		$\frac{A_1B_2+B_1A_2}{B_1+B_2}$	$\frac{B_1B_2}{B_1+B_2}$	$C_1+C_2+\frac{(A_1-A_2)(D_2-D_1)}{B_1+B_2}$	$\frac{B_1D_2+D_1B_2}{B_1+B_2}$

NOTE: The leakage current of the receiving end transformers should be added vectorially to the load current and the leakage current of the sending end transformers should be added vectorially to the sending end current.

GENERAL EQUATIONS—$E_S = E_RA+I_RB$; $E_R = E_SD-I_SB$; $I_S = I_RD+E_RC$; $I_R = I_SA-E_SC$. As A Check In The Numerical Calculation Of The A, B, C and D Constants Note That In All Cases $AD-BC=1$.

system and the exciting kv.a. of the transformer is thus accurately taken into account in the general equations of voltage and current without separate consideration. In order to determine the general circuit constants for a transmission line with transformers at each end, taking into account the exciting admittance of the transformers, the combination would be treated as in Network No.16, for three networks in series, the constants for the end networks being those of Network No. 3 and for the middle network, those of Network No. 4.

The use of the exact network for the transformers leads to a very complex and cumbersome expression for the general circuit constants, requiring a large amount of numerical calculation with corresponding likelihood of error. A further difficulty in its application is that the exciting admittance of a transformer is not known with a high degree of exactness and besides is not constant, but varies with the voltage and load conditions. Since these conditions are known in advance for only one end of the line, the true exciting admittance for one of the transformers can only be determined by trial and error. Assuming as a first approximation that the exciting admittances are equal at both ends of the line and are as determined from the known end conditions, the constants and the unknown voltage can be found on this basis. A new value of exciting admittance can then be determined for the unknown end and a re-calculation of constants and a second solution for voltage and load conditions made.

For the reasons noted and due to limitations of space, the general circuit constants for the exact network are not included in the table. Their values will be found, however, under item (t) of the table on p. 358 of the Electric Journal for August, 1921.

The second method of taking transformers into account is that indicated in Networks 6, 7 and 8. In this method only the impedances of the transformers are considered as network constants, the exciting kv.a. being considered as part of the load on the system. Thus, the exciting current of the receiving end transformers is added to the receiver load and the exciting current of the sending end transformers is treated as a separate load at the sending end. This method gives a very close approximation and as will be seen from the table, the expressions for the general circuit constants are quite simple. It will also be seen that changes of exciting admittance with changes in voltage are easily taken into account.

It is important to note that in applying the table of general circuit constants to particular cases the impedances and constants must be reduced to the same voltage basis. That is, in combining transformer impedances as in Networks 6, 7 and 8 the impedances must be expressed in terms of the voltage at the side of the transformer to which the general network is connected. It is useful for this purpose to note the relation

$$Z_{lv} = \frac{Z_{hv}}{T^2}$$

where Z_{lv} and Z_{hv} are the impedances in terms of low voltage and high voltage, respectively, and T is the ratio of high voltage to low voltage.

In Network No. 14 the constants as tabulated correspond to the case where the intermediate impedance, Z, is a reactor or the impedance of a 1:1 ratio transformer. In the case of a transformer with a ratio T other than unity, the constants become:

$$A = TA_1A_2 + \frac{C_1B_2}{T} + TC_1A_2Z_1$$

$$B = TB_1A_2 + \frac{D_1B_2}{T} + TD_1A_2Z_1$$

$$C = TA_1C_2 + \frac{C_1D_2}{T} + TC_1C_2Z_1$$

$$D = TB_1C_2 + \frac{D_1D_2}{T} + TD_1C_2Z_1$$

where Z_1 = Impedance in terms of voltage of receiving end network.

$$T = \frac{\text{Voltage of sending end network}}{\text{Voltage of receiving end network}}.$$

The A, B, C and D constants in terms of low voltage (Network No. 9), are simply the constants in terms of high voltage (Network No. 8) multiplied by simple functions of the transformer ratios T_r and T_s. The terms low voltage and high voltage are used here and in Networks Nos. 8 and 9 for brevity, since these networks will usually represent the case of a transmission line with raising transformers at the sending end and lowering transformers at the receiving end. In the most general case the relative position of the raising and lowering transformers might be reversed or there might be either raising or lowering transformers at both ends. To make the constants of Networks 8 and 9 applicable to any case it is only necessary to define the transformer ratios T_r and T_s in more general terms, as follows:

$$T_r = \frac{\text{Voltage on network side of transformers at receiving end}}{\text{Voltage on opposite side of transformers at receiving end}}.$$

$$T_s = \frac{\text{Voltage on network side of transformers at sending end}}{\text{Voltage on opposite side of transformers at sending end}}.$$

Corresponding to these definitions the constants of Network No. 8 are those in terms of the voltage on the Network side of the transformers and those of Network No. 9 are in terms of the voltage on the opposite side of the transformers.

Intermediate Loads

In the previous discussion it has been assumed that there are no intermediate loads on the lines or networks to which the various constants apply. Frequently this condition will not exist and it is desirable to extend the method to take account of intermediate loads.

A load of i amperes can be expressed as the product of a voltage e and an admittance y, thus

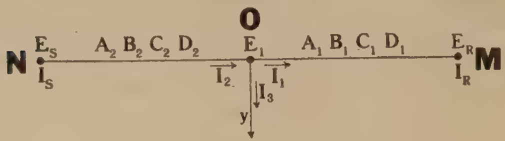
$$i = ey$$

or

$$y = \frac{i}{e}.$$

Assume, as in the figure below, a line between M and N, having a load at O represented by the admittance y,

and constants for the sections to the right and left of O as indicated in the figure. The sections MO and NO may be simple lines or general networks of any kind.



$$\text{Then } E_1 = E_rA_1 + I_rB_1$$

$$\text{Current to right of } O,\ I_1 = I_rD_1 + E_rC_1$$

$$\begin{aligned}\text{Current to left of } O,\ I_2 &= I_1 + I_3 = I_rD_1 + E_rC_1 + E_1y \\ &= I_rD_1 + E_rC_1 + (E_rA_1 + I_rB_1)y \\ &= I_r(D_1 + B_1y) + E_r(C_1 + A_1y) \\ &= I_rD + E_rC\end{aligned}$$

The effect of a load admittance y at the sending end of any section of line or network is thus taken into account in the constants of that section by substituting constants C and D for constants C_1 and D_1

where
$$C = C_1 + A_1y$$
$$D = D_1 + B_1y$$

constants A and B being unaffected.

Referring to the table of general circuit constants it will be seen that the above conditions for an intermediate load are represented by Network No. 11, which network may be substituted, therefore, for any intermediate section of line or network having a load at its sending end.

There is a practical difficulty in assigning the correct value of the admittance y to represent an intermediate load, in that the magnitude of the voltage at the load point is not known in advance. A fairly close estimate can usually be made, however, that will give sufficiently accurate results in most cases, or where higher accuracy is essential the admittance can be determined by the trial and error method.

General Case of Networks in Parallel

The equations of Network No. 17 give directly the constants for two general networks in parallel, and by repeated application of these equations the constants for any number of networks in parallel can be determined. As the number of parallel networks increases this method becomes lengthy and tedious and equations derived by Prof. T. R. Rosebrugh* are more convenient. With a change of nomenclature and using small letters to denote the constants of the individual networks, these equations are:

$$A = \frac{\sum a \times \frac{1}{b}}{\sum \frac{1}{b}} \qquad B = \frac{1}{\sum \frac{1}{b}}$$

$$C = \Sigma c - \Sigma(a-1)(d-1) \times \frac{1}{b} + \frac{\sum(a-1) \times \frac{1}{b}\sum(d-1) \times \frac{1}{b}}{\sum \frac{1}{b}}$$

$$D = \frac{\sum d \times \frac{1}{b}}{\sum \frac{1}{b}}$$

The A, B and D constants are expressed by Prof. Rosebrugh by means of the following convenient verbal definitions.

A is the weighted mean of the a's using their $1/b$'s as weights.

D is the weighted mean of the d's using their $1/b$'s as weights.

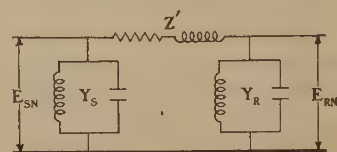
B is the impedance obtained by regarding the b's as impedances connected in parallel.

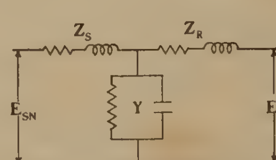
There seems to be no simple interpretation of C but it is the sum of the c's and two terms made up of simple combinations of the quantities $(a - 1)$, $(d - 1)$ and $1/b$.

Equivalent π and Equivalent T in Terms of General Circuit Constants

In combining parallel circuits and in the reduction of complex networks to simple equivalent networks the use of the equivalent π and equivalent T is frequently convenient, and the determination of the equivalent circuits for a smooth line by means of hyperbolic correcting factors has been explained in Chapter X. The equivalent π and equivalent T for a general network can also be expressed conveniently in terms of the general circuit constants, the expressions being derived as follows:

In the general case of an unsymmetrical network the equivalent π is represented, as in the upper diagram of the adjacent figure, by an impedance, Z', shunted,





at the ends, by unequal admittances Y_R and Y_S. These conditions are also represented by Network No. 12 in the table of general circuit constants on page 144, in which the constants A_1, B_1, C_1 and D_1 are those of the impedance Z', viz., $A_1 = 1$, $B_1 = Z'$, $C_1 = 0$, $D_1 = 1$. If we assume any values of Z', Y_R and Y_S and find, from Network No. 12, the corresponding general circuit constants A, B, C and D of the

* Bulletin No. 1, 1919, School of Engineering Research, Toronto University.

network, then, conversely, the assumed values of Z', Y_R and Y_S will represent the equivalent π of any network having the constants A, B and C and D. Thus, from Network No. 12,

$$A = 1 + Z'Y_R \qquad C = Y_S + Y_R + Z'Y_RY_S$$
$$B = Z' \qquad D = 1 + Z'Y_S.$$

from which, substituting B for Z' and transposing the equations for A and D, we have

For equivalent π, $Z' = B$.

$$Y_R = \frac{A-1}{B} \qquad Y_S = \frac{D-1}{B}$$

For an unsymmetrical network, the equivalent T is represented, as in the lower diagram of the adjacent figure, by two unequal impedances, Z_R and Z_S in series, shunted at their junction point by an admittance Y. Using Z_1 and Z_2, respectively, in place of Z_R and Z_S, these conditions are represented by the lower diagram, for Impedance and Admittance, on page 142. In terms of Z_R and Z_S the constants for this network, as given on page 142 are

$$A = 1 + Z_SY$$
$$B = Z_R + Z_S + Z_RZ_SY$$
$$C = Y$$
$$D = 1 + Z_RY$$

from which, substituting C for Y and transposing the expressions for A and D we have

For equivalent T, $Y = C$

$$Z_R = \frac{D-1}{C}$$
$$Z_S = \frac{A-1}{C}$$

Check on Accuracy of Constants

A simple and valuable check on the accuracy of the numerical work in calculating the constants is given by the relation $AD - BC = 1$. The proof is as follows:

For an impedance, the constants of which are as in Network 1, we have

$$AD - BC = 1 \times 1 - Z \times O = 1$$

For an admittance, with constants as in Network 2,

$$AD - BC = 1 \times 1 - O \times Y = 1$$

For a transformer, combining impedance and admittance, with constants as in Network 3,

$$AD - BC = \left(1 + \frac{Z_tY_t}{2}\right)\left(1 + \frac{Z_tY_t}{2}\right) - Z_t\left(1 + \frac{Z_tY_t}{4}\right)Y_t$$

which also reduces to 1.

For a uniform, smooth transmission line, the constants, as in Network 4, are

$$A = \operatorname{Cosh} \sqrt{ZY}$$
$$B = \sqrt{\frac{Z}{Y}} \operatorname{Sinh} \sqrt{ZY}$$
$$C = \sqrt{\frac{Y}{Z}} \operatorname{Sinh} \sqrt{ZY}$$
$$D = A = \operatorname{Cosh} \sqrt{ZY}$$

from which $AD = A^2 = \operatorname{Cosh}^2 \sqrt{ZY}$

$$BC = \sqrt{\frac{Z}{Y}}\sqrt{\frac{Y}{Z}} \operatorname{Sinh}^2 \sqrt{ZY} = \sqrt{1} \operatorname{Sinh}^2 \sqrt{ZY} = \operatorname{Sinh}^2 \sqrt{ZY}$$

and $AD - BC = A^2 - BC = \operatorname{Cosh}^2\sqrt{ZY} - \operatorname{Sinh}^2 \sqrt{ZY} = 1$

For two networks in series, with constants as in Network 13, we have

$$AD - BC = (A_1A_2 + C_1B_2)(B_1C_2 + D_1D_2) - (B_1A_2 + D_1B_2)(A_1C_2 + C_1D_2)$$

which reduces to

$$AD - BC = (A_1D_1 - B_1C_1)(A_2D_2 - B_2C_2)$$

from which it will be seen that the relation holds for the series combination of any two networks for which the relation holds individually.

For two networks in parallel, as in Network 17, we have

$$AD - BC = \frac{(A_1B_2 + B_1A_2)(B_1D_2 + D_1B_2)}{(B_1 + B_2)^2} - \frac{B_1B_2}{B_1 + B_2}\left\{C_1 + C_2 + \frac{(A_1 - A_2)(D_2 - D_1)}{B_1 + B_2}\right\}$$

Expanding and noting that if, in the individual networks $A_1D_1 - B_1C_1 = 1$, etc., then $B_1C_1 = A_1D_1 - 1$, and $B_2C_2 = A_2D_2 - 1$, the above expression reduces to $\frac{(B_1 + B_2)^2}{(B_1 + B_2)^2}$, or 1.

Since any network can be built up from combinations in series and parallel of series impedances, shunt admittances and uniform smooth transmission lines, it follows that the relation $AD - BC = 1$ holds for any network so formed.

In applying the check, it is to be noted that the tables of auxiliary constants at the back of the book are three figure tables, so that any general circuit constants based on these tables will be limited to three figure accuracy. In general, therefore, the check will be uncertain in the third decimal place, the value of $AD - BC$ lying between $1.001 \pm j.001$ and $0.999 \pm j.001$.

Voltage and Current Relations

In equations (5) and (6) the sending end voltage and current are each expressed in terms of the circuit constants and receiving end voltage and current, and in equations (7) and (8) the receiving end voltage and current are expressed in terms of the circuit constants and sending end voltage and current. By transposition and substitution in these equations any one of the four quantities E_s, I_s, E_r and I_r can be expressed in terms of the circuit constants and any two of the remaining three quantities, permitting a choice of equations, in particular cases, for convenience in calculation. Thus,

$$E_s = I_s\frac{A}{C} - I_r\frac{1}{C} \qquad (40)$$

$$E_r = I_s\frac{1}{C} - I_r\frac{D}{C} \qquad (41)$$

give the terminal voltages of a line or section of network in terms of the terminal currents.

$$I_s = E_s\frac{D}{B} - E_r\frac{1}{B} \quad (42)$$

$$I_r = E_s\frac{1}{B} - E_r\frac{A}{B} \quad (43)$$

give the terminal currents in terms of the terminal voltages. Also

$$E_s = E_r\frac{1}{D} + I_s\frac{B}{D} \quad (44)$$

$$E_r = E_s\frac{1}{A} - I_r\frac{B}{A} \quad (45)$$

give the terminal voltages in terms of the current at the same end and the voltage at the remote end.

Equations (5), (6), (7), (8) and (40) to (45) apply also to a group of any number of circuits in parallel, if the general circuit constants of the group and the total currents are used. Thus, the terminal voltages or currents are obtained directly, as in the case of an individual circuit. Convenient equations for calculating the currents in individual branches are derived below.

Assuming a group of any number of parallel circuits we have, from (42) for current in the nth circuit,

$$I_{sn} = E_s\frac{D_n}{B_n} - E_r\frac{1}{B_n} \quad (46)$$

which by substitution for E_s as in (5) reduces to

$$I_{sn} = E_r\frac{AD_n - 1}{B_n} + I_r\frac{BD_n}{B_n} \quad (47)$$

giving the supply end current in an individual circuit in terms of receiving end voltage and total current.

Similarly, from (43)

$$I_{rn} = E_s\frac{1}{B_n} - E_r\frac{A_n}{B_n} \quad (48)$$

which reduces to

$$I_{rn} = E_r\left(\frac{A - A_n}{B_n}\right) + I_r\frac{B}{B_n} \quad (49)$$

giving the receiving end current in an individual circuit in terms of the receiving end voltage and total current.

Numerical Example

A useful example by which to illustrate the method of solution by general circuit constants is the 220 kv. problem which has been dealt with fully by the "step-by-step" method in the preceding chapter, since the solution of this problem, both analytically and graphically, by both methods, can be compared directly.

Referring to the solutions in the preceding chapter, it will be noted that in the complete solution for the case of normal load, the exciting kv.a. of both the sending and receiving end transformers has been treated as separate loads. This corresponds to the conditions represented in Network No. 8 of the table of general circuit constants, in which the impedances only of the transformers are treated as constants of the network.

Referring to the data of this problem on Chart XXIII and considering only the complete solution for the case of normal load, the following conditions are specified at the receiving end, all values being to neutral and referred to voltage at the load side of the transformer as the vector of reference:

$$\text{Load voltage} = E_{ln} = 127{,}020 \text{ volts.}$$

$$\text{Total current} = I_r = 203.39 - j17.87 = 204.17 \diagdown 5^\circ\,01'\,16'' \text{ amperes}$$

$$\text{Transformer impedance} = Z_{tr} = Z_{ts} = 3.185 + j39.82$$

$$\begin{aligned} \text{Line constants } A_{line} &= .893955 + j.020234 \\ B_{line} &= 32.198 + j172.094 \\ C_{line} &= -.000008 + j.001168 \end{aligned}$$

Also, since the line is symmetrical, $D = A$. As a check on the values of the line constants $A^2 - BC = 1.00002 - j.000054$.

From the above values we derive the following quantities:

$$\begin{aligned} C_{line} &= -.000008 + j.001168 \\ Z_{ts} &= \underline{3.185 \quad + j39.82} \\ & \quad -.000025 + j.0037201 \\ & \quad \underline{-.046510 - j.0003186} \\ C_{line}Z_{ts} &= -.046535 + j.0034015 \\ Z_{tr} &= \underline{3.185 \quad + j39.82} \\ & \quad -.14821 + j\,.0108 \\ & \quad \underline{-.13545 - j1\ 8530} \\ C_{line}Z_{tr}Z_{ts} &= -.28366 - j1\,.8422 \end{aligned}$$

Also,

$$\begin{aligned} A_{line} &= .893955 + j.020234 \\ Z_{tr} &= \underline{3.185 \quad + j39.82} \\ & \quad 2.8472 + j.064 \\ & \quad \underline{-\ .8057 + j35.597} \\ A_{line}Z_{tr} &= 2.0415 + j35.661 \end{aligned}$$

And since $A = D$ and $Z_{tr} = Z_{ts}$, $AZ_{tr} = DZ_{ts}$.

Referring now to the equations for Network No. 8, the general circuit constants are found as follows:

$$\begin{aligned} A_{line} &= .893955 + j.020234 \\ C_{line}Z_{ts} &= \underline{-.046535 + j.003401} \\ A &= .84742 \quad + j.023635 \\ B_{line} &= 32.198 \quad + j172.094 \\ A_{line}Z_{tr} &= 2.0415 + j35.661 \\ D_{line}Z_{ts} &= 2.0415 + j35.661 \\ C_{line}Z_{tr}Z_{ts} &= \underline{-\ .2837 - j1.842} \\ B &= 35.9973 + j241.574 \\ C = C_{line} &= -.000008 + j.001168 \\ D = A &= .84742 \quad + j.023635 \end{aligned}$$

The check here is $AD - BC = 1.000008 - j.000055$.

The voltage at the generator side of the sending end transformer is then determined from equation (5), as follows:

$$\begin{aligned} E_{gen-n} &= 127{,}020(.84742 + j.023635) + (203.39 - j17.87)(35.9973 + j241.574) \\ &= (107{,}639 + j3002) + (11638 + j48490) \\ &= 119{,}277 + j51{,}492 \\ &= 129{,}917 / 23^\circ\,20'\,59'' \end{aligned}$$

The line current at the sending end is determined from equation (6) as follows:

$$\begin{aligned}I_s &= (203.39 - j17.87)(.84742 + j.023635) + \\ &\qquad 127{,}020(-.000008 + j.001168) \\ &= (172.78 - j10.33) + (-1.02 + j148.36) \\ &= 171.76 + j138.03 \\ &= \underline{220.35/38^\circ\, 47'\, 10''} \text{ amp.}\end{aligned}$$

The exciting current of the sending end transformer is now to be added to I_s to give the total current at the generators. This is given in the data of the problem as $(1.81 - j13.6)$ amp. to E_{gen} as the vector of reference. Referred to E_{ln}, the vector of reference in the above solution, the angle between E_{ln} and E_{gen} being $23^\circ\ 20'\ 56''$ we have for I_{ts} at the sending end:

$$\begin{aligned}I_{ts} &= (1.81 - j13.6)(\cos + j \sin)\ 23^\circ\ 20'\ 56'' \\ &= (1.81 - j13.6)(.918 + j.3964) \\ &= 7.05 - j11.77 \text{ amperes to vector } E_{ln}\end{aligned}$$

Then

$$\begin{aligned}I_s &= 171.76 + j138.03 \\ \underline{I_{ts}} &= \underline{\ \ 7.05 - \ \ j11.77} \\ I_{gen} &= 178.81 + j126.26 \\ &= \underline{218.89/35^\circ\ 13'\ 35''} \text{ amp.} \\ KW_{gen-n} &= 119.276 \times 178.81 + 51.495 \times 126.26 \\ &= 27{,}830.\end{aligned}$$

The above values of E_{gen-n} and I_{gen} agree within one unit in the last figure with the values as determined by the "step-by-step" method in the preceding chapter, which, with allowance for the small differences arising in the numerous steps of the calculation by the latter method may be considered as an absolute check.

The high accuracy of the solution by Network No. 8 is indicated by the following comparison of the above results with those obtained by using constants based on the exact representation of the transformers as in Network No. 3.

	By Exact Network	By Network No. 8	Error Per Cent
E_{gen-n}	130,019	129,917	−.077
I_{gen}	218.61	218.89	+.125
KW_{gen-n}	27,837	27,830	−.025

Graphical Solution

A graphical solution of the preceding problem, using general circuit constants, is given on the following page and may be compared with the "step-by-step" vector solution shown on Chart XXIII in the preceding chapter.

In comparing the graphical with the numerical solution it is to be noted that in the numerical solution all quantities are calculated in terms of E_{ln}, the load voltage as the vector of reference. In a graphical solution both the numerical calculations and construction of the diagram are simplified by changing the vector of reference. In the general circuit constant diagram, the steps actually followed in the graphical solution are drawn in solid lines, while the corresponding values used in the numerical solution are shown by dotted lines.

Comparison of Methods

Comparing the numerical work of the preceding solution by general circuit constants with the "step-by-step" solution on Chart XXIII, it will be noted that in the case of a single line with transformers, the solution by general circuit constants, including the determination of the constants, is considerably shorter as well as more simple and direct and no trigonometrical work is required other than the determination of the angles of E_{gen} and I_{gen}. The "step-by-step" solution can be greatly shortened and simplified, however, and trigonometrical work eliminated, by making all calculations in terms of the load voltage as the vector of reference. In this way, the work by the two methods is approximately equalized.

While the use of general circuit constants is essential for analysis by means of the circle diagram, and practically so in the case of networks, the "step-by-step" solution has the advantage of showing what is happening in all parts of the circuit, while the other methods show only the terminal conditions; and for the solution of single line problems for only one condition of load and voltage the "step-by-step" method would ordinarily be preferable. Where a general analysis of a line is to be made under several conditions of load and voltage, time will be saved and chances of error reduced by the use of general circuit constants.

Comparing the graphical solutions by the two methods, it will be noted that the same steps are required in the construction of the current diagram by both methods. The voltage diagram is simplified with general circuit constants, by the elimination of the two impedance triangles for the transformers.

THE CIRCLE DIAGRAM

The current and power circle diagrams, for a smooth line or general network of any character, under steady state conditions and in terms of load conditions at either the receiving or sending end, are derived from equations (5) and (6) on page 141. In the following analysis absolute or scalar values will be represented by E_r, I_r, etc., complex, or vectorial values by $\dot{E}_r$, $\dot{I}_r$, etc. and conjugates by $\underset{\smile}{E}_r$, $\underset{\smile}{I}_r$, etc., the conjugate of a vector being defined as the vector with the sign of its imaginary or j term changed. The equations are based on voltage to neutral and power per phase.

The Current Diagram

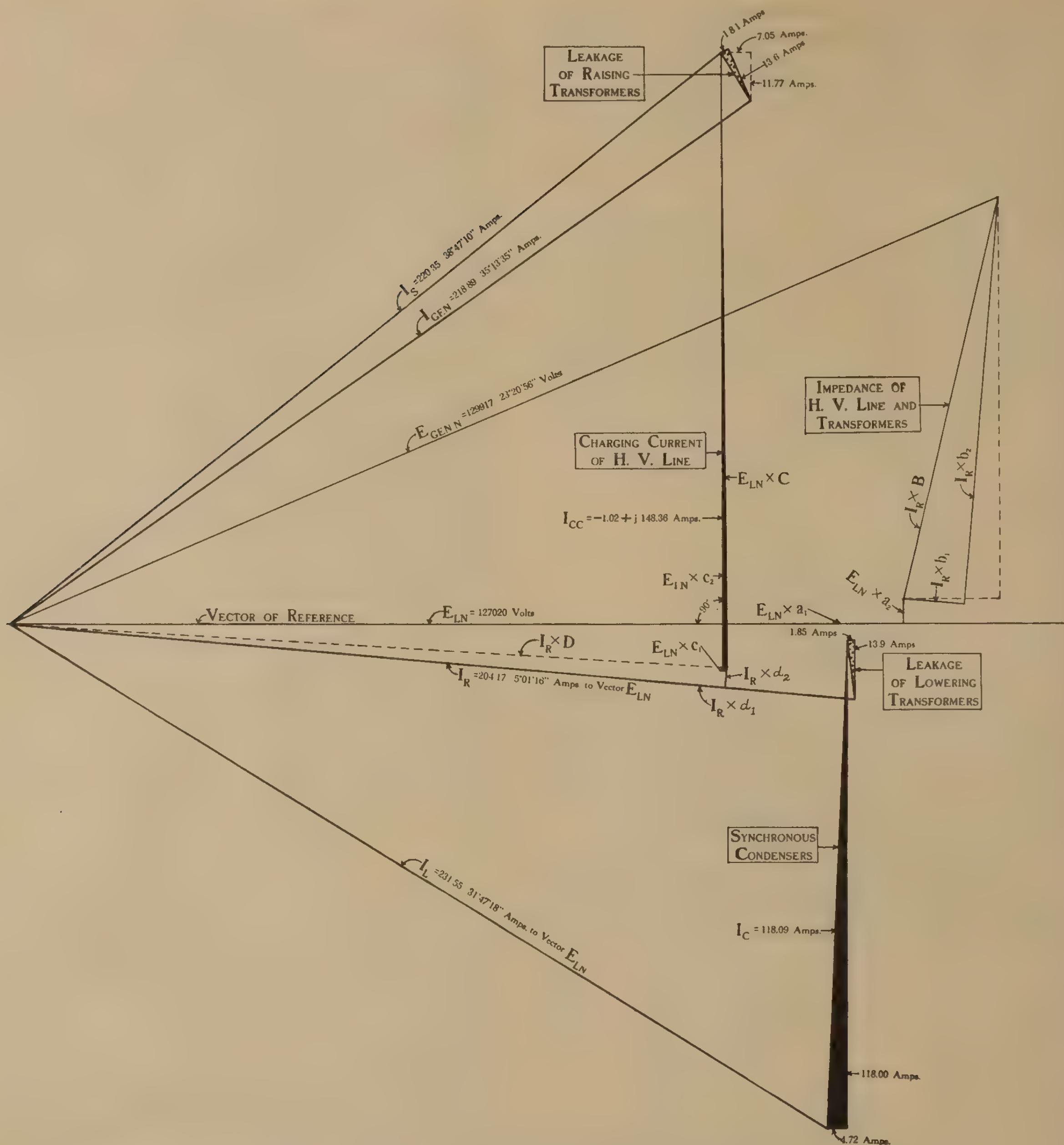
In the above nomenclature equations (5) and (6) would be written

$$\begin{aligned}\dot{E}_s &= \dot{E}_r\dot{A} + \dot{I}_r\dot{B} \\ \dot{I}_s &= \dot{I}_r\dot{D} + \dot{E}_r\dot{C}\end{aligned}$$

By transposition and substitution these may be written

$$\dot{I}_r = \dot{E}_s \times \frac{1}{\dot{B}} - \dot{E}_r \times \frac{\dot{A}}{\dot{B}} \tag{50}$$

$$\dot{I}_s = \dot{E}_s \times \frac{\dot{D}}{\dot{B}} - E_r\Big(\frac{\dot{A}\dot{D} - \dot{B}\dot{C}}{\dot{B}}\Big) \tag{51}$$



Graphical solution of 220 Kv. problem by general circuit constants.

and since $\dot{A}\dot{D} - \dot{B}\dot{C} = 1$, equation (51) may be written

$$\dot{I}_s = \dot{E}_s \times \frac{\dot{D}}{\dot{B}} - \dot{E}_r \times \frac{1}{\dot{B}} \qquad (52)$$

If $\dot{E}_r$ is taken as the vector of reference for equation (50), then $\dot{E}_r = E_r = E_r$. If the angle by which the sending end voltage leads the receiving end voltage is θ_v, it is evident that $\dot{E}_s = E_s\ (\cos\theta_v + j\sin\theta_v)$. Substituting in equation (50), we have

$\dot{I}_r$(to vector E_r) =

$$E_s \times \frac{1}{\dot{B}}(\cos\theta_v + j\sin\theta_v) - E_r \times \frac{\dot{A}}{\dot{B}} \qquad (53)$$

With E_r and E_s constant, it will be seen that $\dot{I}_r$ is the sum of a fixed vector $-E_r \times \dot{A}/\dot{B}$ and a vector $E_s \times 1/\dot{B}$ multiplied by the quantity $(\cos\theta_v + j\sin\theta_v)$. Since the magnitude of $(\cos\theta_v \pm j\sin\theta_v)$ is always equal to unity, multiplying by $(\cos\theta_v \pm j\sin\theta_v)$ does not affect the magnitude of a vector, its only effect being to rotate the vector through an angle θ_v, in a direction corresponding to the sign of the imaginary, or j term. It will be seen, therefore, that the locus of the sum of the two vectors of (53), or $\dot{I}_r$, is a circle with its center at $-E_r \times \dot{A}/\dot{B}$ and a radius whose length is $E_s \times 1/B$.

The sending end current can be expressed by an equation similar to (53) in terms of the same vector of reference, E_r. A more symmetrical expression is obtained, however, the form of the diagram improved and numerical work somewhat shortened and simplified by expressing the sending end current in terms of the sending end voltage as the vector of reference. If $\dot{E}_s$ is taken as the vector of reference for equation (52) then $\dot{E}_s = E_s = E_s$ and $\dot{E}_r = E_r(\cos\theta_v - j\sin\theta_v)$. It will be realized that the receiving end voltage lags behind the sending end voltage by the angle θ_v, as indicated by the minus sign of the imaginary term. Substituting in equation (52) we have

$$\dot{I}_s \text{ (to vector } E_s) = E_s \times \frac{\dot{D}}{\dot{B}} - E_r \times \frac{1}{\dot{B}}(\cos\theta_v - j\sin\theta_v) \qquad (54)$$

It will be seen from equation (54) that the locus of $\dot{I}_s$ is a circle with its center at $E_s \times \dot{D}/\dot{B}$ and a radius whose length is equal to $E_r \times 1/B$.

For convenience in making numerical computations, and in plotting the diagram, equations (53) and (54) may be written in the form:

$$\dot{I}_r \doteq nE_s(\sin\theta_b - j\cos\theta_b)\ (\cos\theta_v + j\sin\theta_v) - (l - jm)E_r \qquad (55)$$

$$\dot{I}_s = -nE_r(\sin\theta_b - j\cos\theta_b)\ (\cos\theta_v - j\sin\theta_v) + (l' - jm')E_s \qquad (56)$$

in which

$$n(\sin\theta_b - j\cos\theta_b) = \frac{1}{\dot{B}},\ \text{or}\ n = \frac{1}{B}$$

$$l - jm = \frac{\dot{A}}{\dot{B}}$$

$$l' - jm' = \frac{\dot{D}}{\dot{B}}$$

The construction of the current circle diagram based on the preceding equations is illustrated in Fig. 76, the angles in the various circle diagram figures and equations being as defined below. In the definitions the "slope" of a constant means the angle between the constant and its real component, considered as a vector of reference.

θ_a = Slope of constant $\dot{A}$.
θ_b = Complement of the slope of constant $\dot{B}$.
θ_d = Slope of constant $\dot{D}$.
θ_v = Angle by which $\dot{E}_s$ leads $\dot{E}_r$.

Points A and B are the centers, respectively, of the receiving and sending end circles with co-ordinates, based on equations (55) and (56), as shown. OA, produced, is the line of centers for all receiving end circles.

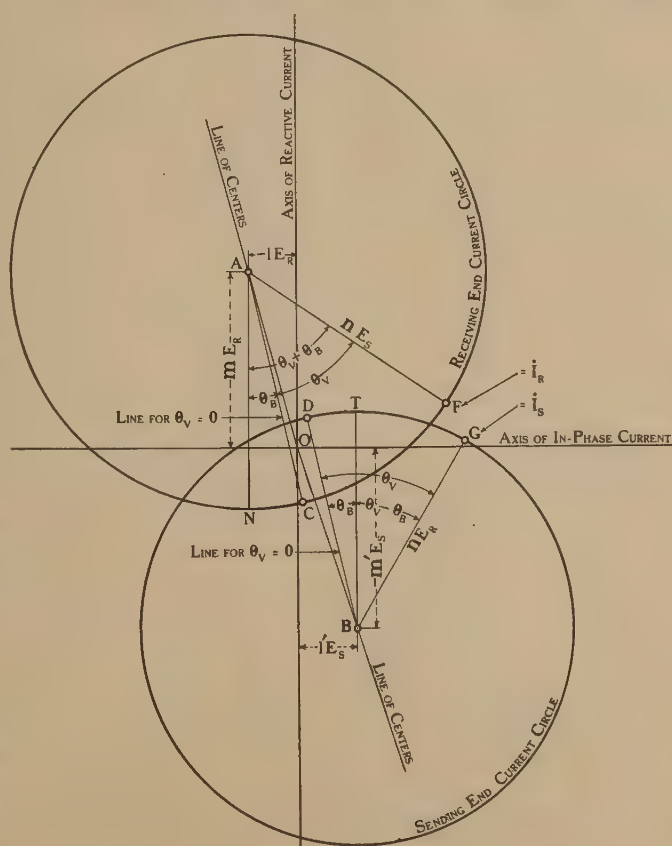


FIG. 76.

The slope of this line as determined by the fraction $-\frac{\dot{A}}{\dot{B}}$ is $(\theta_a + \theta_b + 90°)$, and the centers lie along this line at a distance from 0 directly proportional to E_r. Similarly OB, produced, is the line of centers of sending end circles, its slope being $(\theta_d + \theta_b - 90°)$ and the centers lie along this line at a distance from 0 directly proportional to E_s. The radius of receiving end circles is nE_s and its slope, when $\theta_v = 0$, is $(\theta_b - 90°)$ as determined by the fraction $\frac{1}{\dot{B}}$. The length of

the sending end radius is nE_r and its slope, when $\theta_v = 0$, is $(90° + \theta_b)$, as determined by the fraction $-\frac{1}{\dot{B}}$.

Points C and D show, respectively, the receiving and sending end current for the condition $\theta_v = 0$. Rotating the radius AC through the angle θ_v and the radius BD through the angle $-\theta_v$, the corresponding values of $\dot{I}_r$ and $\dot{I}_s$ are determined, as at F and G, for any value of θ_v.

The diagram in Fig. 76 represents an unsymmetrical circuit, as indicated by the angle between the lines of centers of the two circles. It may be noted that for a smooth line or symmetrical network, in which $\dot{D} = \dot{A}$ the slopes of the two lines will be equal and the centers of both circles will lie on the same straight line through the origin. For lines or networks electrically short, in which capacity can be neglected and without shunt admit-

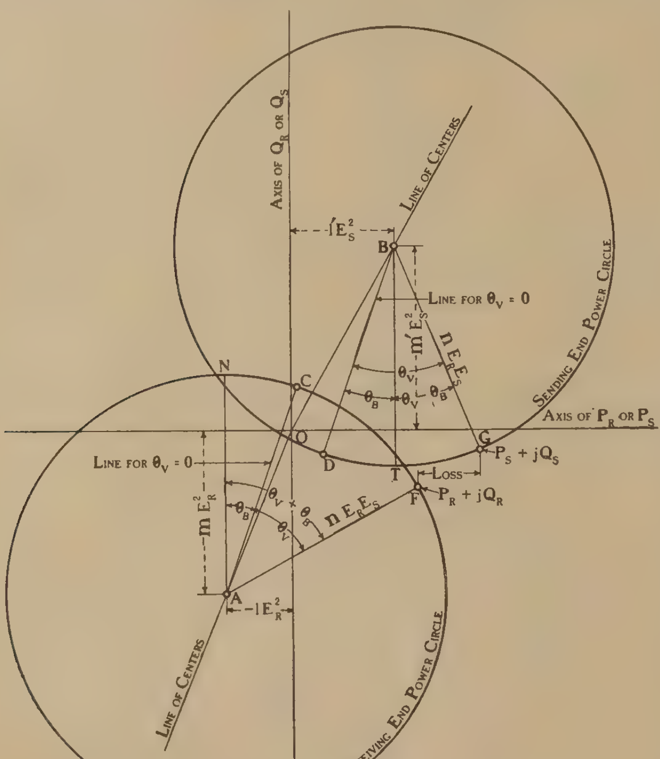


Fig. 77.

tances, all circuits become electrically symmetrical and $\dot{D} = \dot{A} = 1$. If, in addition, the terminal voltages are equal, not only do the centers lie on the same straight line through the origin, but the circles have equal radii and also pass through and become tangent at the origin. This would apply to short sections of lines or networks on which level voltage is maintained.

The Power Diagram

In alternating current circuits power is not, as in direct current circuits, the product of voltage and current or $\dot{E} \times \dot{I}$. The explanation of this is rather involved but the point is treated quite fully by Charles Fortescue in the Appendix to his paper on the "Measurement of Power in Polyphase Circuits."* Power (real P and reactive Q) in alternating current circuits is, instead, the product of voltage and the conjugate of the current, or $\dot{E} \times \underset{\cdot}{I}$.

Changing equations (50) and (52) to the conjugate form and multiplying the conjugate of (50) by $\dot{E}_r$ and the conjugate of (52) by $\dot{E}_s$, the power at the receiving and sending ends is then obtained as follows:

$$P_r + jQ_r = \dot{E}_r\underset{\cdot}{I}_r = \dot{E}_r\underset{\cdot}{E}_s \times \frac{1}{\underset{\cdot}{B}} - \dot{E}_r\underset{\cdot}{E}_r \times \frac{\underset{\cdot}{A}}{\underset{\cdot}{B}} \quad (57)$$

$$P_s + jQ_s = \dot{E}_s\underset{\cdot}{I}_s = \dot{E}_s\underset{\cdot}{E}_s \times \frac{\underset{\cdot}{D}}{\underset{\cdot}{B}} - \dot{E}_s\underset{\cdot}{E}_r \times \frac{1}{\underset{\cdot}{B}} \quad (58)$$

With $\dot{E}_r$ as the vector of reference $\dot{E}_r = \underset{\cdot}{E}_r = E_r$ and $\dot{E}_s = E_s(\cos\theta_v + j\sin\theta_v)$. In addition, $\dot{E}_r\underset{\cdot}{E}_r = E_r^2$, $\dot{E}_s\underset{\cdot}{E}_s = E_s^2$ and $\underset{\cdot}{E}_s = E_s(\cos\theta_v - j\sin\theta_v)$. Substituting in (57) and (58) we have

$$P_r + jQ_r = \frac{E_rE_s(\cos\theta_v - j\sin\theta_v)}{\underset{\cdot}{B}} - E_r^2 \times \frac{\underset{\cdot}{A}}{\underset{\cdot}{B}} \quad (59)$$

$$P_s + jQ_s = E_s^2 \times \frac{\underset{\cdot}{D}}{\underset{\cdot}{B}} - \frac{E_rE_s(\cos\theta_v + j\sin\theta_v)}{\underset{\cdot}{B}} \quad (60)$$

Equations (59) and (60) are in a form similar to equations (53) and (54) for current, from which it follows that with E_r and E_s constant the locus of the point $P_r + jQ_r$ is a circle with its center at $-E_r^2 \times \underset{\cdot}{A}/\underset{\cdot}{B}$ and a radius whose length is E_rE_s/B. Similarly, from (60), with E_r and E_s constant, the locus of $P_s + jQ_s$ is a circle with its center at $E_s^2 \times \underset{\cdot}{D}/\underset{\cdot}{B}$ and a radius whose length is E_rE_s/B.

Equations (59) and (60) can be written in the form

$$P_r + jQ_r = nE_rE_s\,(\sin\theta_b + j\cos\theta_b)\,(\cos\theta_v - j\sin\theta_v) - (l + jm)E_r^2 \quad (61)$$

$$P_s + jQ_s = (l' + jm')E_s^2 - nE_rE_s\,(\sin\theta_b + j\cos\theta_b)\,(\cos\theta_v + j\sin\theta_v) \quad (62)$$

in which

$$n\,(\sin\theta_b + j\cos\theta_b) = 1/\underset{\cdot}{B} \text{ or } n = 1/B$$

$$l + jm = \frac{\underset{\cdot}{A}}{\underset{\cdot}{B}}$$

$$l' + jm' = \frac{\underset{\cdot}{D}}{\underset{\cdot}{B}}$$

The coefficients above are the conjugates of the corresponding coefficients in current equations (55) and (56), the numerical values of the components being identical in both cases.

The construction of the Power Circle Diagram is illustrated in Fig. 77, the same letters being used to denote corresponding points in the current and power diagrams. A and B are the centers, respectively, of the receiving and sending end circles, with coordinates, as in equations (61) and (62). The slope of the vector $-E_r^2\underset{\cdot}{A}/\underset{\cdot}{B}$ is $270° - (\theta_a + \theta_b)$ so that the line of centers, OA, of receiving end circles is at an angle $-(\theta_a + \theta_b)$

* Transactions A. I. E. E., February, 1923, Vol. XLII, p. 364.

from the Q axis. Similarly, the slope of E_s^2D/B is 90° $-(\theta_d + \theta_b)$, which fixes the line of centers OB, of sending end circles, at an angle $-(\theta_d + \theta_b)$ from the Q axis.

The radii of both circles have the same length, *viz.*, nE_rE_s, in which n is the absolute value of $1/B$. When $\theta_v = 0$ the value of $(\cos \theta_v \pm j \sin \theta_v)$ in (61) and (62) is unity and the radius of receiving end circles is the vector $nE_rE_s (\sin \theta_b + j \cos \theta_b)$. This is represented by the line AC at an angle $NAC = \theta_b$. Similarly, for $\theta_v = 0$ the radius of sending end circles is the vector $-nE_rE_s (\sin \theta_b + j \cos \theta_b)$ which is represented by BD at an angle $TBD = \theta_b$. It will be seen that AC and BD will always be parallel, which affords a check on the determination of points C and D.

Having determined, at C, the receiving end power for the condition $\theta_v = 0$ the value of $P_r + jQ_r$ for any other value of θ_v is determined as at F, by laying off, in a negative direction, the angle $CAF = \theta_v$. The corresponding power at the sending end is determined as at G by laying off, in a positive direction the angle $DBG = \theta_v$. Since the radii of both circles are equal the chords CF and DG are equal, so that chord measurement gives a simple and accurate means of plotting equal angles in the two circles. The transmission losses are shown by the difference between the P components of points F and G.

The diagram in Fig. 77 represents an unsymmetrical line or network, as indicated by the angle between the lines of centers of the two circles. For symmetrical circuits and short lines without capacity and shunt admittances the same conditions apply as stated in the last paragraph of the previous section on The Current Diagram.

Referring to the expressions for the centers and radii of the circles it will be seen that when the voltage at either end is held constant the center of the corresponding circle will be constant and the radius will vary in proportion to the voltage at the remote end. So that a constant voltage at one end, with different voltages at the other end can be represented by a family of concentric circles for the constant voltage end. With varying voltage at either end the circle center for that end will move along the line of centers, its distance from the origin being proportional to the square of the voltage at that end.

As previously noted, the equations of the power circle diagram have been derived on the basis of voltage to neutral and power per phase. Since each of the terms in equations (61) and (62) is proportional to E_r^2, E_s^2, or E_rE_s it will be seen that if, in the case of a three phase circuit, the line voltages, *viz.*, $\sqrt{3}E_r$ and $\sqrt{3}E_s$ are substituted each term of the power equations will be multiplied by $\sqrt{3}^2$ or 3, so that by using line voltages the same equations can be used to give the total power.

It is to be noted that all equations for the circle diagram are based on volts, amperes, watts and volt-amperes as units. In plotting the power diagram, however, it will usually be convenient to use a scale of kilowatts and kilovolt-amperes, in which case all of the calculated quantities should be divided by 1,000.

The Loss Diagram

The transmission losses being the difference between sending and receiving end power, may be obtained graphically from the power circle diagram as indicated in Fig. 77. However, this method of obtaining losses is not very accurate since it requires the graphical determination of a small difference between two large quantities. A more accurate method, particularly applicable to power circle diagrams, is the Loss Diagram developed by Mr. C. F. Wagner. His derivation and graphical interpretation of the loss equation is very simple and requires only a single additional calculation and the addition of a straight line to the power diagram.

The difference between the true power at the sending and receiving ends represents the transmission losses of the circuit. Thus, letting L = the transmission losses, we can write

$$L = P_s - P_r$$

The true power at the two ends of the circuit is equal to the real parts of equations (61) and (62) from which we get

$$P_s = l'E_s^2 - nE_rE_s \ (\sin \theta_b \cos \theta_v - \cos \theta_b \sin \theta_v)$$
$$P_r = -lE_r^2 + nE_rE_s \ (\sin \theta_b \cos \theta_v + \cos \theta_b \sin \theta_v)$$

Subtracting,

$$L = lE_r^2 + l'E_s^2 - 2nE_rE_s \sin \theta_b \cos \theta_v \qquad (63)$$

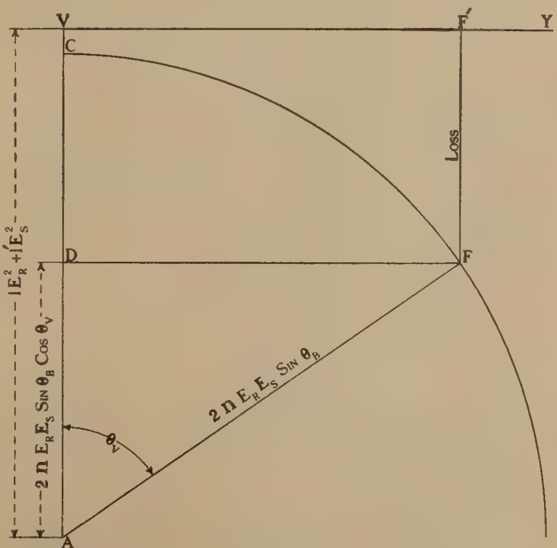


Fig. 78.

Equation (63) is represented graphically in Fig. 78 in which the length of AV is made equal to the sum of the constant terms lE_r^2 and $l'E_s^2$ and the radius, AF, of the circular arc is made equal to $2nE_rE_s \sin \theta_b$. The third, and variable term of the equation is then represented by AD, the projection on AV of the radius AF, at an angle θ_v to AV. The loss, for this value of θ_v, is the difference between AV and AD, and is represented in the figure by the line FF', drawn normal to VY from F.

The loss diagram can be drawn to any scale, so that by a suitable choice of scale the radius AC of the loss circle can be made equal to radius AC of the power circle

in Fig. 77. By orienting the loss diagram so that the AC lines in both diagrams coincide, the loss and power circles will coincide and the losses can then be shown on the power diagram by simply extending the radius AC in Fig. 77, for $\theta_v = 0$, to a length, on the loss scale, equal to $lE_r^2 + l'E_s^2$ and drawing from its end a line perpendicular to AC.

Since the same radius is to represent on the loss scale the quantity $2nE_rE_s \sin \theta_b$ and on the power scale the quantity nE_rE_s, we have for the relation between the two scales.

$$\text{Ratio of loss scale to power scale} = \frac{2nE_rE_s \sin \theta_b}{nE_rE_s} = 2 \sin \theta_b$$

Since the radii of the receiving and sending end power circles are equal it is evident that the loss line VY of Fig. 78 can also be drawn on the power diagram in an identical relation to the sending end power circle and the radius BD. By drawing both lines on the power diagram the losses can then be shown based on either the receiving or sending end load conditions. As the radii AC and BD are always parallel the loss lines, drawn perpendicular to these radii, will also be parallel. The complete construction as described is shown on the Loss Diagram for the 220 kv. problem (Fig. 80) in the Numerical Example which follows.

Loss in Terms of Conditions at One End and Conditions for Minimum Loss

The preceding loss equations are expressed in terms of the voltage at both ends of the circuit. In the following the loss equations in terms of conditions at one end only and the conditions for minimum transmission losses are derived.

Equations (5) and (6) are

$$\dot{E}_s = \dot{E}_r\dot{A} + \dot{I}_r\dot{B} \quad (5)$$
$$\dot{I}_s = \dot{I}_r\dot{D} + \dot{E}_r\dot{C} \quad (6)$$

The conjugate of (6) is

$$\underset{\cdot}{I}_s = \underset{\cdot}{I}_r\underset{\cdot}{D} + \underset{\cdot}{E}_r\underset{\cdot}{C} \quad (64)$$

Multiplying (5) and (64) we get

$$\dot{E}_s\underset{\cdot}{I}_s = \dot{E}_r\underset{\cdot}{E}_r\dot{A}\underset{\cdot}{C} + \dot{E}_r\underset{\cdot}{I}_r\dot{A}\underset{\cdot}{D} + \underset{\cdot}{E}_r\dot{I}_r\dot{B}\underset{\cdot}{C} + \dot{I}_r\underset{\cdot}{I}_r\dot{B}\underset{\cdot}{D} \quad (65)$$

But $\dot{E}\underset{\cdot}{E} = E^2$; $\dot{E}\underset{\cdot}{I} = P + jQ$ and $\underset{\cdot}{E}\dot{I} = P - jQ$.

Substituting in (65), with the proper subscripts,

$$P_s + jQ_s = E_r^2\dot{A}\underset{\cdot}{C} + (P_r + jQ_r)\dot{A}\underset{\cdot}{D} + (P_r - jQ_r)\dot{B}\underset{\cdot}{C} + I_r^2\dot{B}\underset{\cdot}{D} \quad (66)$$

Noting that

$$P_s = P_r + L \text{ and } I_r^2 = \frac{P_r^2 + Q_r^2}{E_r^2},$$

substituting in (66) and transposing, we get

$$L + jQ_s = P_r(\dot{A}\underset{\cdot}{D} + \dot{B}\underset{\cdot}{C} - 1) + E_r^2\dot{A}\underset{\cdot}{C} + \left(\frac{P_r^2 + Q_r^2}{E_r^2}\right)\dot{B}\underset{\cdot}{D} + Q_rj(\dot{A}\underset{\cdot}{D} - \dot{B}\underset{\cdot}{C}) \quad (67)$$

Considering only the real parts of (67) we have

$$L = tP_r + uE_r^2 + v\left(\frac{P_r^2 + Q_r^2}{E_r^2}\right) + wQ_r \quad (68)$$

in which t = real part of $(\dot{A}\underset{\cdot}{D} + \dot{B}\underset{\cdot}{C} - 1) = a_1d_1 + a_2d_2 + b_1c_1 + b_2c_2 - 1$

u = real part of $\dot{A}\underset{\cdot}{C} = a_1c_1 + a_2c_2$
v = real part of $\dot{B}\underset{\cdot}{D} = d_1b_1 + d_2b_2$
w = real part of $j(\dot{A}\underset{\cdot}{D} - \dot{B}\underset{\cdot}{C}) = a_1d_2 - a_2d_1 - b_1c_2 + b_2c_1$.

it being noted that the small letters, with subscripts, in the right hand terms are the real and imaginary components of the general circuit constants A, B, C and D, or $A = a_1 + ja_2$; $B = b_1 + jb_2$; $C = c_1 + jc_2$; $D = d_1 + jd_2$.

It will be seen that equation (68) gives the losses in terms of receiving end conditions and the general circuit constants and it is not necessary to know the sending end voltage as in equation (63). A similar derivation gives the following equation for losses in terms of sending end conditions.

$$L = -tP_s + u'E_s^2 + v'\left(\frac{P_s^2 + Q_s^2}{E_s^2}\right) - w'Q_s \quad (69)$$

in which t has the same numerical value as above and

u' = real part of $\dot{D}\underset{\cdot}{C} = d_1c_1 + d_2c_2$
v' = real part of $\underset{\cdot}{A}\dot{B} = a_1b_1 + a_2b_2$
w' = real part of $j(\underset{\cdot}{A}\dot{D} - \dot{B}\underset{\cdot}{C}) = d_1a_2 - d_2a_1 - b_1c_2 + b_2c_1$

It may be noted that the difference between the coefficients for sending and receiving end conditions consists simply in the substitution of $\dot{D}$ for $\dot{A}$ and $\underset{\cdot}{A}$ for $\underset{\cdot}{D}$. In a symmetrical circuit, therefore, where $\dot{D} = \dot{A}$ the coefficients will be the same for both ends. Also the first two terms of the expanded expression for w will be equal and of opposite sign, so that

$$w = w' = -b_1c_2 + b_2c_1$$

The real part of the expression for t is not affected by the substitution of $\dot{D}\underset{\cdot}{A}$ for $\dot{A}\underset{\cdot}{D}$, so that the numerical value of t is the same for both ends of the circuit, as stated above.

From equation (68) the condition for minimum transmission loss for assigned values of receiving end power and voltage is determined by differentiating the loss equation with respect to Q_r. Thus, from (68)

$$\frac{dL}{dQ_r} = \frac{2vQ_r}{E_r^2} + w.$$

For minimum loss $\frac{2vQ_r}{E_r^2} + w = 0$, or

$$Q_r = -\frac{w}{2v}E_r^2 \quad (70)$$

The value of Q_r for minimum loss is therefore constant for all values of P_r and can be shown on the power circle diagram by a line parallel to and distant $-\frac{w}{2v}E_r^2$ from, the P axis.

If the receiving end voltage is maintained then the sending end voltage must vary with the power transmitted in order to keep Q_r constant and the loss a minimum. Hence, by drawing on the power circle diagram concentric circles for various sending end voltages and a constant receiving end voltage it is possible to determine very quickly the values of sending end voltages required for different receiving end loads in order to keep the transmission losses to a minimum.

By a similar analysis the condition for minimum loss in terms of sending end conditions is found by equating to zero the differential of equation (69) with respect to Q_s. Thus

$$\frac{dL}{dQ_s} = \frac{2v'Q_s}{E_s^2} - w' = 0$$

from which

$$Q_s = \frac{w'}{2v'}E_s^2 \qquad (71)$$

The line of minimum loss in terms of sending end conditions is therefore a line parallel to and at a distance $\frac{w'}{2v'}E_s^2$ from the P axis.

The line of minimum loss for receiving end conditions is shown on the Loss Diagram, Fig. 80.

It may be pointed out that equations (68) and (69) are the same as the loss equations given by Messrs. Evans and Sels in their original articles, to which reference is made on page 141, and are the basis of their Loss Circle Diagram. Since loss and efficiency have a simple relation it follows that similar Efficiency Circle Diagrams may also be derived. For a discussion of these loss and efficiency circle diagrams the reader is referred to the original articles by Messrs. Evans and Sels.

Equations for Circle Diagrams and for General Use in Numerical Calculations

For convenient reference the various circle diagram equations derived in the preceding pages are collected below and following them are equations for use in calculating the various quantities required for the construction of the diagrams and for general use in the determination of current, power and angle relations. The latter equations are readily derived from the definitions given in the preceding text and from the geometry of Figs. 76, 77 and 78.

Current Equations.

$$\dot{I}_r \text{ (to vector } E_r) = nE_s(\sin\theta_b - j\cos\theta_b)(\cos\theta_v + j\sin\theta_v) - (l - jm)E_r$$

$$\dot{I}_s \text{ (to vector } E_s) = (l' - jm')E_s - nE_r(\sin\theta_b - j\cos\theta_b)(\cos\theta_v - j\sin\theta_v)$$

Power Equations.

$$P_r + jQ_r = nE_rE_s(\sin\theta_b + j\cos\theta_b)(\cos\theta_v - j\sin\theta_v) - (l + jm)E_r^2$$

$$P_s + jQ_s = (l' + jm')E_s^2 - nE_rE_s(\sin\theta_b + j\cos\theta_b)(\cos\theta_v + j\sin\theta_v)$$

Loss Equations.

In terms of conditions at both ends

$$L = P_s - P_r = lE_r^2 + l'E_s^2 - 2nE_rE_s\sin\theta_b\cos\theta_v$$

In terms of conditions at receiving end

$$L = tP_r + uE_r^2 + v\left(\frac{P_r^2 + Q_r^2}{E_r^2}\right) + wQ_r$$

In terms of conditions at sending end

$$L = -tP_s + u'E_s^2 + v'\left(\frac{P_s^2 + Q_s^2}{E_s^2}\right) - w'Q_s$$

For minimum loss in terms of receiving end conditions

$$Q_r = -\frac{w}{2v}E_r^2$$

For minimum loss in terms of sending end conditions,

$$Q_s = \frac{w'}{2v'}E_s^2$$

Coefficients.

$$l = \frac{a_1b_1 + a_2b_2}{b_1^2 + b_2^2}$$

$$m = \frac{a_1b_2 - a_2b_1}{b_1^2 + b_2^2}$$

$$l' = \frac{d_1b_1 + d_2b_2}{b_1^2 + b_2^2}$$

$$m' = \frac{d_1b_2 - d_2b_1}{b_1^2 + b_2^2}$$

$$n = \frac{1}{\sqrt{b_1^2 + b_2^2}}$$

$$t = a_1d_1 + a_2d_2 + b_1c_1 + b_2c_2 - 1$$

$$u = a_1c_1 + a_2c_2$$

$$v = d_1b_1 + d_2b_2$$

$$w = a_1d_2 - a_2d_1 - b_1c_2 + b_2c_1$$

$$u' = d_1c_1 + d_2c_2$$

$$v' = a_1b_1 + a_2c_2$$

$$w' = d_1a_2 - d_2a_1 - b_1c_2 + b_2c_1$$

Angles.

$$\theta_a = \tan^{-1}\frac{a_2}{a_1}$$

$$\theta_b = \tan^{-1}\frac{b_1}{b_2}$$

$$\theta_d = \tan^{-1}\frac{d_2}{d_1}$$

$$\theta_v = \cos^{-1}\frac{b_1(lE_r^2 + P_r) + b_2(mE_r^2 + Q_r)}{E_rE_s}$$

$$= \cos^{-1}\frac{b_1(l'E_s^2 - P_s) + b_2(m'E_s^2 - Q_s)}{E_rE_s}$$

Current Quantities.

Letting I_{pr}, I_{ps} = In-phase component of current at receiving and sending ends.

I_{qr}, I_{qs} = Reactive component of current at receiving and sending ends.

$$I_{pr} = nE_s\sin(\theta_v + \theta_b) - lE_r$$

$$\text{Theoretical limit} = nE_s - lE_r$$

$$I_{qr} = nE_s\cos(\theta_v + \theta_b) + mE_r$$

$$I_{ps} = nE_r\sin(\theta_v - \theta_b) + l'E_s$$

$$I_{rs} = nE_r\cos(\theta_v - \theta_b) - m'E_s$$

Power Quantities.

$$P_r = nE_rE_s\sin(\theta_v + \theta_b) - lE_r^2$$

$$\text{Theoretical limit} = nE_rE_s - lE_r^2$$

$$Q_r = nE_rE_s\cos(\theta_v + \theta_b) - mE_r^2$$

$$P_s = nE_rE_s\sin(\theta_v - \theta_b) + l'E_s^2$$

$$Q_s = nE_rE_s\cos(\theta_v - \theta_b) + m'E_s^2$$

Numerical Example

As an example to illustrate the circle diagram method for the solution of transmission problems a complete numerical solution of the 220 kv. problem by this method is given below. The Power Circle Diagram is shown in Fig. 79, the Loss Diagram in Fig. 80 and the Current Circle Diagram in Fig. 81.

It will be apparent that the circle diagram method is not primarily intended for the determination of voltage and current at one end of a circuit from known conditions at the other end, but that this method is based on the pre-determination or assumption of voltage conditions at both ends of the circuit. In the present example the values determined in the previous solution of the 220 kv. problem by General Circuit Constants are used as the basis of the circle diagram solution.

In the original problem in Chapter XIV the calculations for emergency conditions were based on a change of transformer connections to carry the emergency load. This results in a change in the value of the general circuit constants as found for normal load conditions. In order, however, to avoid the complication that would result in the attempt to represent normal and emergency load conditions, with different constants on the same diagram, it is assumed, in the present case, that there is no change in transformer connections under emergency load, thus giving a single set of circuit constants for all load conditions. While this is not a practical operating condition its assumption greatly simplifies the construction of the diagram without impairing its value for illustration.

Power Diagram Calculations

Referring to the previous solution of the 220 kv. problem in this chapter by general circuit constants, we have, under normal load conditions:

General Circuit Constants

$$\begin{aligned} A &= .84742 + j.023635 \\ B &= 35.997 + j241.57 \\ C &= -.000008 + j.001168 \\ D = A &= .84742 + j.023635 \end{aligned}$$

$E_r = 127{,}020$

$E_s = 129{,}917$

and

$E_r^2 = 16{,}134{,}000{,}000$

$E_s^2 = 16{,}878{,}000{,}000$

$E_rE_s = 16{,}502{,}000{,}000$

From equations (61), and (62) and for a symmetrical circuit,

$$l + jm = l' + jm' = \frac{.84742 - j.023635}{35.997 - j241.57}$$
$$= .00060709 + j.0034175$$
$$n = \frac{1}{\sqrt{35.997^2 + 241.57^2}} = .0040944$$

from which

$$\begin{aligned} -lE_r^2 &= -.00060709 \times 16134 \times 10^6 = -\ 9{,}795{,}000 \\ -mE_r^2 &= -.0034175 \times 16134 \times 10^6 = -55{,}138{,}000 \\ nE_rE_s &= .0040944 \times 16502 \times 10^6 = 67{,}566{,}000 \end{aligned}$$

giving the center co-ordinates and the radius of the receiving end power circle.

Also

$$\begin{aligned} l'E_s^2 &= .00060709 \times 16878 \times 10^6 = 10{,}247{,}000 \\ m'E_s^2 &= .0034175 \times 16878 \times 10^6 = 57{,}682{,}000. \end{aligned}$$

giving the center co-ordinates of the sending end power circle, the radius being the same as at the receiving end.

Referring to Fig. 79 and noting that the diagram is plotted to a scale of kw. and kv.a., while the calculated quantities are in watts and volt-amperes, the center of the receiving end power circle is plotted at A, with co-ordinates of $-9{,}795$ and $-55{,}138$ as derived above. With center at A, the receiving end power circle $NCFL$ is drawn with a radius $nE_rE_s = 67{,}566$ as above.

Similarly, the sending end power circle $DGKR$ is drawn with center at B, having co-ordinates of 10,247 and 57,682 and a radius of 67,566, as above.

The points C and D are next determined, either from the angle θ_b or from the horizontal component of the radius which gives a more accurate determination of C. The values are

$$\theta_b = \tan^{-1}\frac{35.997}{241.57} = 8° \, 28' \, 30''$$

Radius $\times \sin 8° \, 28' \, 30'' = 67{,}566 \times .14738 = 9{,}958$.

The angle θ_v, between E_r and E_s, as previously determined, is 23° 20′ 59″ and by laying off this angle from the radius AC the receiving end power is determined at F as

$$P_r + jQ_r = 25{,}835 + j2{,}270$$

Laying off the same angle 23° 30′ 59″ from BD the corresponding power at the sending end is determined at G as

$$P_s - jQ_s = 27{,}595 - j7{,}620$$

In the foregoing solution the load at F is determined for a given phase angle θ_v. In most cases, as in the original solution of the 220 kv. problem, load conditions are assumed from which the sending end voltage and phase angle are determined. Starting with the assigned load conditions we have for the power load and transformer exciting current.

$$\begin{aligned} I_l &= 196.82 - j121.97 \\ I_t &= \underline{\ \ 1.85 - j\ 13.90} \\ &\ 198.67 - j135.87 \end{aligned}$$

Adding to the above the in-phase component of condenser current of 4.72 amp. gives a receiving end load, exclusive of the reactive kv.a. of the condenser of $203.39 - j135.87$ amperes, for which

$$\text{Load} = 127{,}020(203.39 + j135.87) = 25{,}835 + j17{,}258$$

This load is represented at E on Fig. 79 at a power factor represented by the diagonal OE, of 83.26 per cent. The point E, however, is not on the circle for the assigned sending end voltage of 129,917, the voltage corresponding to radius AE being 155,150. In order that the load point E may fall on the circle leading reactive kv.a. must be supplied by the condenser, as indicated by the line EF. The line EF represents 14,988 kv.a., giving a total load at F for the assigned voltages, of $25{,}835 + j2{,}270$. The angle θ_v can then be determined graphically, and its value, of course, checks with that previously determined by calculation.

Having determined the receiving and sending end power the transmission losses are the difference between the true power or $P_s - P_r$, the losses in this case being 1,760 kw., as shown on the diagram.

Under emergency load conditions, with a single bank of transformers, we have

$$I_l = 393.64 - j243.94$$
$$I_t = \quad 1.85 - \quad j13.90$$
$$I_c = \quad 16.53 + j413.01 \text{ (see page 134).}$$

$$I_r = 412.02 + j155.17$$

$$E_s = 127{,}020(.84742 + j.023635) + (412.02 + j155.17)(35.997 + j241.57)$$
$$= 84{,}986 + j108{,}120$$
$$= 137{,}523/51^\circ\ 50' \text{ volts.}$$
$$E_s^2 = 18{,}913{,}000{,}000$$
$$l'E_s^2 = .00060709 \times 18{,}913 \times 10^6 = 11{,}482{,}000$$
$$m'E_s^2 = .0034175 \times 18{,}913 \times 10^6 = 64{,}635{,}000$$
$$nE_rE_s = .0040944 \times 127{,}020 \times 137{,}523 = 71{,}522{,}000$$

From centers A and B', with radius 71,522, the emergency load power circles are drawn, as in the case of normal load. The receiving end circles are concentric, while the sending end circles, having different voltages, are non-concentric.

The receiving end power load, transformer exciting kv.a. and condenser losses under emergency load conditions are then determined in the same way as for normal load conditions, the load as shown at H being 52,335 + j32,751 with a power factor of 84.78 per cent. Power factor correction to bring H on to the emergency load power circle requires 52,461 leading reactive kv.a., as indicated, giving a receiving end load at J, of $P_r' - jQ_r' = 52{,}335 - j19{,}710$. Laying off the angle $D'B'K$ equal to angle $C'AJ$, or chord $D'K$ equal to chord $C'J$, the sending end power is determined at K as

$$P_s' + jQ_s' = 60{,}586 + j12{,}633$$

The losses $= P_s' - P_r'$, $= 60{,}586 - 52{,}335$ or 8,251 kw., as indicated on the diagram.

It is apparent that the theoretical limit of power which can be delivered over the line with the assigned voltages is represented at L for normal load voltage, the corresponding sending end load being at R, the limiting loads and corresponding losses being

$$P_r'' - jQ_r'' = 57{,}771 - j55{,}138$$
$$P_s'' + jQ_s'' = 74{,}878 + j37{,}986$$
$$\text{Loss} = P_s'' - P_r'' = 17{,}107 \text{ kw.}$$

Corresponding limiting load points under emergency load voltage conditions are indicated at M and S.

It should be noted that the theoretical limits of power mentioned apply only to the line itself, under steady state conditions. The actual limit of power, in a given case, will be determined by the characteristics of the load and apparatus as, for instance, voltage regulators, governors, etc., connected to the system. In other words, the limit of power is for the line only, under the constant assigned voltages, and not for the transmission system.

In connection with the diagram it is to be noted that the use of the conjugate of current in determining power results in a reversal of sign for leading and lagging components of power so that all points above the axis of true power represent lagging kv.a. and all points below represent leading kv.a., as shown at the left of the diagram.

Loss Diagram Calculations

The basis of the Loss Diagram, Fig. 80, is the Power Diagram of Fig. 79, for normal load conditions only, to which the loss line is added. From the previous analysis we have,

On loss scale

$$AV = lE_r^2 + l'E_s^2 = 9{,}795 + 10{,}247$$
$$= 20{,}042 \text{ kw.}$$

On power scale

$$AV = \frac{20{,}042}{2 \sin 8^\circ\ 28'\ 30''} = \frac{20{,}042}{2 \times .14738}$$
$$= 67{,}985 \text{ kw.}$$

Having determined point V the loss line VL', for receiving end conditions, is drawn normal to AV. The loss for the normal receiving end load at F is then shown on the loss scale, by the perpendicular FF', drawn from F to the loss line.

A separate loss scale being required, it is convenient to lay off this scale along the radius AV, so that the loss can be read directly as the projection of the load points on AV, as indicated by the dotted lines. The loss at V being 0 the loss scale for receiving end conditions is marked off toward A, using the relation previously derived of

$$\text{Loss Scale} = \text{Power Scale} \times 2 \sin 8^\circ\ 28'\ 30''$$

An identical relation with the sending end power circle is shown by the loss line WR', the loss scale being laid off from W along the radius BW.

Since the loss per unit length is 2 sin θ_b times the power per unit length, inversely, the length of the loss scale will be $\frac{1}{2 \sin \theta_b}$ times the length of the power scale for a given value. For a value of $\sin \theta_b = .5$ the scales and scale lengths will be equal, while for values of sin θ_b less than .5 the length of the loss scale will be greater than the length of the power scale, for the same value. In the present case $\frac{1}{2 \sin 8^\circ\ 28'\ 30''} = 3.39$ which is the relative length of the loss measurement as shown by the lines FF' and GG' and the loss shown as the difference $P_s - P_r$ along the P axis.

The loss for normal load conditions and for the theoretical limit of power under normal load voltage conditions are shown by the dotted projections of the points F, G, L and R on the loss scales.

The value of Q_r for the line of minimum loss shown on the diagram is determined from equation (70) in which, as defined for equation (68), and for a symmetrical circuit

$$v = .84742 \times 35.997 + .023635 \times 241.57$$
$$= 36.214$$
$$w = -35.997 \times .001168 + 241.57 \times -.000008$$
$$= -.043977$$

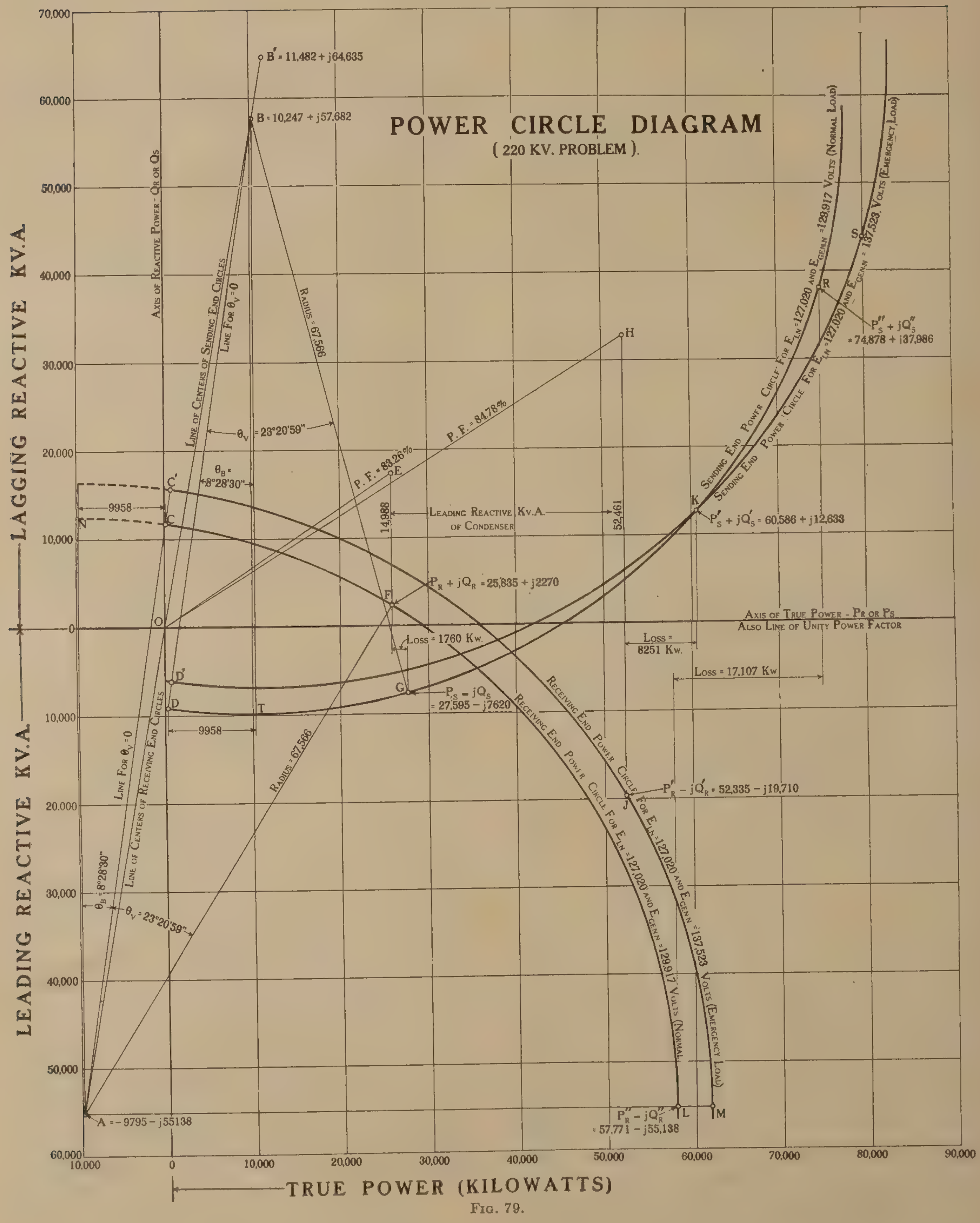

POWER CIRCLE DIAGRAM
(220 KV. PROBLEM).
LAGGING REACTIVE KV.A.
LEADING REACTIVE KV.A.
TRUE POWER (KILOWATTS)
B' = 11,482 + j64,635
B = 10,247 + j57,682
Axis of Reactive Power - QR or QS
Line of Centers of Sending End Circles
Line for θV = 0
Radius = 67,566
θV = 23°20'59"
θB = 8°28'30"
P. F. = 84.78%
P. F. = 83.26%
Leading Reactive Kv.A. of Condenser
14,988
52,461
9958
PR + jQR = 25,835 + j2270
Axis of True Power - PR or PS
Also Line of Unity Power Factor
Loss = 1760 Kw.
Loss = 8251 Kw.
Loss = 17,107 Kw
PS - jQS = 27,595 - j7620
P'S + jQ'S = 60,586 + j12,633
P''S + jQ''S = 74,878 + j37,986
Sending End Power Circle for ELN = 127,020 and EGENN = 129,917 Volts (Normal Load)
Sending End Power Circle for ELN = 127,020 and EGENN = 137,523 Volts (Emergency Load)
Receiving End Power Circle for ELN = 127,020 and EGENN = 129,917 Volts (Normal
Receiving End Power Circle for ELN = 127,020 and EGENN = 137,523 Volts (Emergency Load)
P'R - jQ'R = 52,335 - j19,710
P''R - jQ''R = 57,771 - j55,138
A = -9795 - j55138
Line of Centers of Receiving End Circles
Line for θV = 0

Fig. 79.

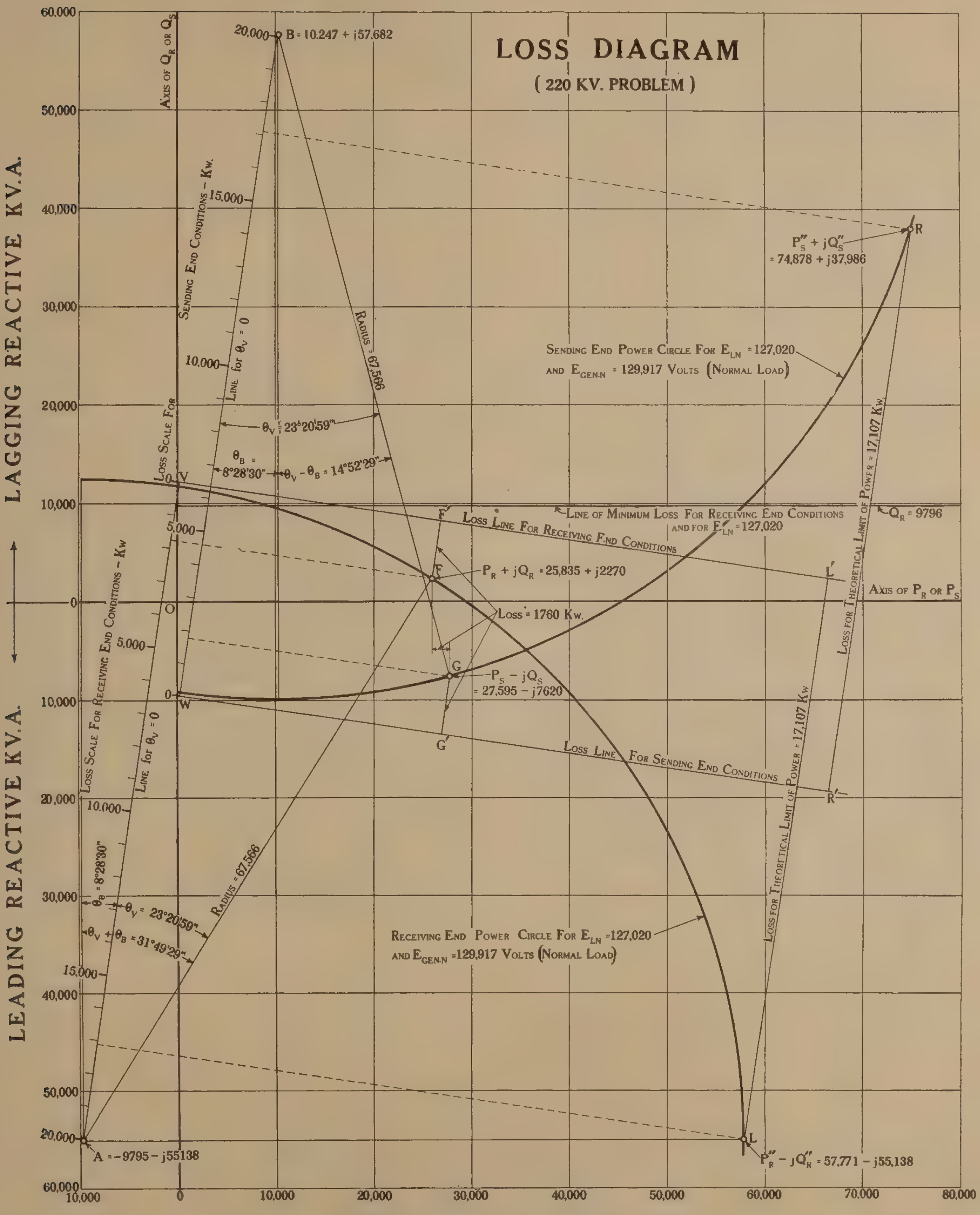

LOSS DIAGRAM
(220 KV. PROBLEM)
LAGGING REACTIVE KV.A.
LEADING REACTIVE KV.A.
TRUE POWER (KILOWATTS)
B = 10.247 + j57.682
Axis of Q_R or Q_S
Sending End Conditions – Kw.
Loss Scale For Receiving End Conditions – Kw
Line for $\theta_V = 0$
Radius = 67,566
$\theta_V = 23°20'59''$
$\theta_B = 8°28'30''$
$\theta_V - \theta_B = 14°52'29''$
$\theta_V + \theta_B = 31°49'29''$
$P''_S + jQ''_S$ = 74,878 + j37,986
Sending End Power Circle For E_{LN} = 127,020 and $E_{GEN\text{-}N}$ = 129,917 Volts (Normal Load)
Line of Minimum Loss For Receiving End Conditions and for E_{LN} = 127,020
Q_R = 9796
Loss Line For Receiving End Conditions
$P_R + jQ_R$ = 25,835 + j2270
Axis of P_R or P_S
Loss = 1760 Kw.
$P_S - jQ_S$ = 27,595 – j7620
Loss Line For Sending End Conditions
Loss for Theoretical Limit of Power = 17,107 Kw
Receiving End Power Circle For E_{LN} = 127,020 and $E_{GEN\text{-}N}$ = 129,917 Volts (Normal Load)
A = –9795 – j55138
$P''_R - jQ''_R$ = 57,771 – j55,138

FIG. 80.

from which, for minimum loss

$$Q_r = -\frac{-.043977}{2 \times 36.214} \times 16,134$$
$$= 9,796$$

CURRENT DIAGRAM CALCULATIONS

From equation (55) and for normal load conditions the center co-ordinates and radius of the receiving end current circle are

$$-lE_r = -.00060709 \times 127,020 = -77.11$$
$$mE_r = .0034175 \times 127,020 = 434.09$$
$$nE_s = .0040944 \times 129,917 = 531.93$$

For the sending end circle the center co-ordinates and radius are, from equation (56),

$$l'E_s = .00060709 \times 129,917 = 78.87$$
$$-m'E_s = -.0034175 \times 129,917 = -443.99$$
$$nE_r = .0040944 \times 127,020 = 520.07$$

In the Current Circle Diagram, Fig. 81, the receiving and sending end current circles for normal load are drawn in heavy lines, with centers and radii as above. Points C and D, for $\theta_v = 0$ are determined from the angle $\theta_b = 8° 28' 30''$ or from the horizontal components of the radii which, as indicated on the diagram are

For receiving end $531.93 \times .14738 = 78.40$
For sending end $520.07 \times .14738 = 76.65$

Plotting the angle $CAF = 23° 20' 59''$, the value of $\dot{I}_r$ is obtained at F, as $203.39 - j17.87$ amp. Or, starting, instead, with assumed load conditions we have, as shown in the power diagram calculations

Load at $E = 203.39 - j135.87$ amp.

The sending end voltage, at E, corresponding to the radius AE, is 150,150 volts. In order to bring E on to the assigned voltage circle it is necessary to supply leading current from the condenser of 118.00 amperes, giving the load at F, for the assigned voltages, of $203.39 - j17.87$ amp. The angle θ_v is then determined graphically as $23° 20' 59''$. Laying this angle off from BD the corresponding sending end current is determined, at G, as $212.40 + j58.65$ amp.

In plotting equal angles in the receiving and sending end circles chord measurement can be used as noted for the power diagram. In the current diagram, however, the radii, and therefore the chords are unequal, being proportional to the radii, for equal angles. Thus, in Fig. 81,

$$\text{Chord } DG = \text{Chord } CF \times \frac{520.07}{531.93}$$

Emergency load conditions are shown by the light circles, for which E_r does not change and $E_s = 137,523$ volts. At the receiving end, therefore, the center co-ordinates are the same as for normal load and the radius is determined by

$$nE_s = .0040944 \times 137,523 = 563.07$$

For the sending end the radius, being fixed by the receiving end voltage, does not change and the center co-ordinates are

$$l'E_s = .00060709 \times 137,523 = 83.49$$
$$-m'E_s = -.0034175 \times 137,523 = -469.98$$

The emergency receiving end load as shown on page 157 is $412.02 + j155.17$. Deducting the leading condenser current of 413.01 amp. the load as plotted at H, without power factor correction, is $412.02 - j257.84$ amp. HJ shows the leading current required to bring the load on to the emergency load voltage circle, this being, of course, 413.01, as calculated and the current at J, $\dot{I}_r'$, is $412.02 + j155.17$ amp. In the same manner as for normal load the corresponding sending end current is determined at K as $440.55 - j91.88$ amp.

Corresponding to the theoretical limit of true power that can be transmitted over the circuit under the assigned voltage conditions the theoretical limit of in-phase current at the receiving end, under normal and emergency load conditions is indicated, respectively, at L and M, the corresponding sending end current being at R and S.

The concentric circles drawn with centers at the origin enable the absolute value of current to be read directly for any point on the diagram.

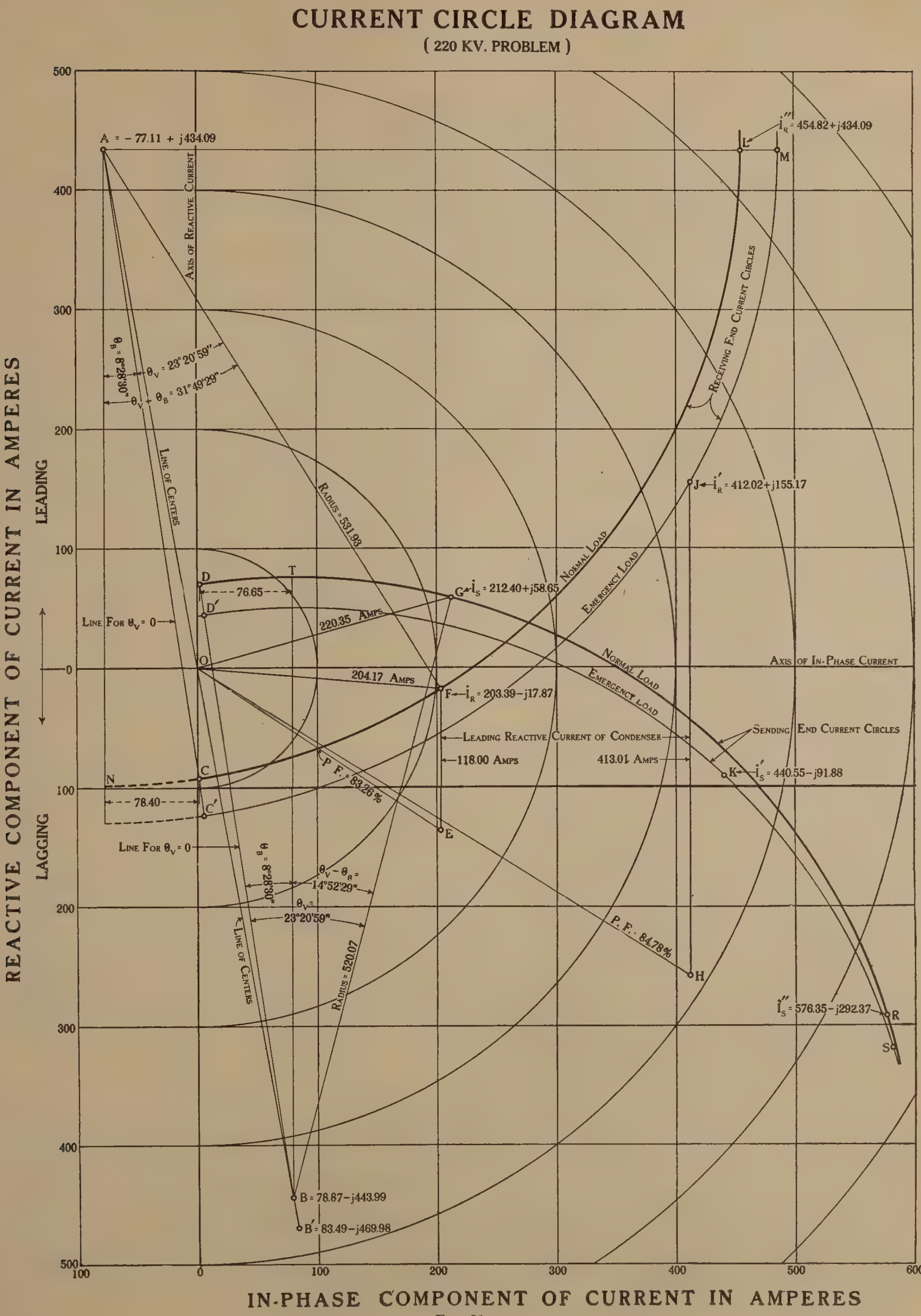

CURRENT CIRCLE DIAGRAM
(220 KV. PROBLEM)
A = −77.11 + j434.09
$i_R''' = 454.82+j434.09$
L
M
Axis of Reactive Current
Receiving End Current Circles
$\theta_B = 8°28'30''$
$\theta_V = 23°20'59''$
$\theta_V + \theta_B = 31°49'29''$
Line of Centers
Radius = 531.93
J
$i_R' = 412.02+j155.17$
Normal Load
Emergency Load
D
T
76.65
G
$i_S = 212.40+j58.65$
D'
Line For $\theta_V = 0$
220.35 Amps
O
204.17 Amps
F
$i_R = 203.39-j17.87$
Axis of In-Phase Current
Sending End Current Circles
Leading Reactive Current of Condenser
118.00 Amps
413.01 Amps
P.F. = 83.26%
K
$i_S' = 440.55-j91.88$
N
C
78.40
C'
E
$\theta_V - \theta_B = 14°52'29''$
$\theta_V = 23°20'59''$
P.F. = 84.78%
H
Radius = 520.07
$i_S'' = 576.35-j292.37$
R
S
B = 78.87−j443.99
B' = 83.49−j469.98
REACTIVE COMPONENT OF CURRENT IN AMPERES
LEADING
LAGGING
IN-PHASE COMPONENT OF CURRENT IN AMPERES

Fig. 81.

CHAPTER XVI

CABLE CHARACTERISTICS

HEATING LIMITS FOR CABLES

The maximum safe limiting temperatures in degrees C. at the surface of conductors in cables is given in the Standardization Rules of the A. I. E. E. (1922) as follows:

For impregnated paper insulation (85 − E)
For varnished cambric (75 − E)
For rubber insulation (60 − 0.25 E)

Where E represents the effective operating e.m.f. in kilovolts between conductors and the numerals represent temperature in degrees C. Thus, at a working pressure of 5 kv., the maximum safe limiting temperature at the surface of the conductors in a cable would be:

For impregnated paper insulation (80°C.)
For varnished cambric insulation (70°C.)
For rubber compound insulation (58.75°C.)

The actual maximum safe continuous current load for any given cable is determined primarily by the temperature of the surrounding medium and the rate of radiation. This current value is greater with direct than with alternating current and decreases with increasing frequency, being less for 60 cycles than for 25 cycles. The carrying capacity of cables will therefore be less in hot climates than in cooler climates and will be considerably increased during the winter.

Cables immersed in water, carry at least 50 per cent more than when installed in a four-duct line, and when buried in the earth 15 to 30 per cent more than in a duct line, depending upon the character of soil moisture, etc. Circulating air or water through conduits containing lead covered cables will increase their capacity. From the above it is evident that no general rule relative to carrying capacity can be formulated to apply in all cases, and it is necessary, therefore, to consider carefully the surroundings when determining the size of cables to be used.

The practicability of tables which specify carrying capacity for cables installed in ducts will generally be questioned, for the reason that operating conditions are frequently more severe than those upon which table values are based. A duct line may operate at a safe temperature throughout its entire length, except at one isolated point adjacent to a steam pipe or excessive local temperatures due to some other cause. If larger cables are not employed at this point, burnouts may occur here when the remainder of the cable line is operating well within the limits of safe operating temperature. The danger in using table values for carrying capacity without carefully considering the condition of earth temperature throughout the entire duct length is thus evident.

HEATING OF CABLES

The basis upon which the accompanying table has been calculated is covered by footnotes below the table. The kv.a. values are determined from the current in amperes and are based upon 30°C. rise and a maximum of 3,000 volts.* Expressing the carrying capacity of cables in terms of kv.a. (corrected for the varying thickness of insulation required for various voltages) may be found more convenient than the usual manner of expressing it in amperes. It will be noted that the kv.a. values of the table are on the basis of a four-duct line and that for more than four ducts in the line the table kv.a. values will be reduced to the following:

For a 4 duct line, 100 per cent.
For a 6 duct line, 88 per cent.
For an 8 duct line, 79 per cent.
For a 10 duct line, 71 per cent.
For a 12 duct line, 63 per cent.
For a 16 duct line, 60 per cent.

When applied to all sizes of cables, the above values are only approximate. The reduction of carrying capacity caused by the presence of many cables is more for large cables than for small ones. Also, where load factors are small, the reduction due to the presence of many cables is less than the value assigned, although the carrying capacity of a small number of cables is only slightly affected.

REACTANCE OF THREE-CONDUCTOR CABLES

The accompanying tables contain values for the inductance, reactance and impedance of round three-conductor cables of various sizes and for the thicknesses of insulation indicated. All values in the tables are on the basis of one conductor of the cable 1 mile long.

The table values were calculated from the fundamental equation (4),

$$L = 0.08047 + 0.741 \log_{10} \frac{D}{R}$$

where L = the inductance in millihenries per mile of each conductor, R the actual radius of the conductor and D the distance between conductor centers expressed in the same units as R. As indicated in Chapter II, under Inductance, this formula has been derived on the basis of solid conductors. In the case of cables, the effective radius is actually slightly less than that of the

* These current values are taken from General Electric *Bulletin* No. 49302, March 1917. They are in general slightly higher than those published by the Standard Underground Cable Co. Handbook, 1906.

CARRYING CAPACITY OF INSULATED COPPER CONDUCTORS

The following values for carrying capacity must not be assumed unless it is positively known that the conditions upon which they are based will not be exceeded in service.

THREE CONDUCTOR CABLES

B & S NO. AREA IN CIRCULAR MILS	XX CARRYING CAPACITY IN AMPERES DIRECT CURRENT BASED UPON 30° C RISE AND A MAXIMUM OF 3000 VOLTS, PAPER INSULATION	K.V.A. WHICH MAY BE TRANSMITTED AT THREE PHASE AND THE FOLLOWING VOLTAGES OVER PAPER INSULATED LEAD COVERED CABLES INSTALLED IN A FOUR DUCT LINE WITH 30° C RISE IN TEMPERATURE BASED UPON THE ASSUMPTION THAT ALL DUCTS CARRY LOADED CABLES AND UPON A NORMAL EARTH TEMPERATURE OF 20° C. FOR A 6 DUCT LINE THESE K.V.A. VALUES WOULD BE REDUCED TO APPROXIMATELY 88 PER CENT FOR AN 8 DUCT LINE TO 79 PER CENT. FOR A 10 DUCT LINE TO 71 PER CENT FOR A 12 DUCT LINE TO 63 PER CENT AND FOR A 16 DUCT LINE (4 WIDE AND 4 HIGH) TO 60 PER CENT OF THE TABLE VALUES. XXXX.																
		220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	3300 VOLTS	4000 VOLTS	6000 VOLTS	6600 VOLTS	10000 VOLTS	11000 VOLTS	12000 VOLTS	13200 VOLTS	15000 VOLTS	20000 VOLTS	22000 VOLTS	25000 VOLTS
14	18	7	14	17	34	68	103	124	184	202	300	328	356	390	438	570	620	693
12	22	8	17	21	42	84	125	152	225	247	367	400	435	477	536	695	757	847
10	30	11	23	28	57	114	171	206	307	336	500	547	595	650	730	950	1035	1155
8	40	15	30	38	76	152	228	275	410	450	667	730	792	867	975	1265	1380	1540
6	55	21	42	52	104	209	314	378	562	616	917	1000	1090	1190	1340	1740	1895	2120
4	70	26	53	66	133	266	400	482	715	785	1170	1275	1385	1520	1710	2215	2410	2700
2	95	36	72	90	180	361	543	655	970	1065	1585	1730	1880	2060	2310	3000	3270	3650
1	110	42	84	105	209	418	628	755	1125	1230	1840	2050	2180	2390	2680	3480	3780	4240
0	130	49	99	123	247	495	740	895	1330	1460	2170	2370	2580	2820	3170	4120	4470	5000
00	150	57	114	143	285	570	855	1030	1535	1710	2500	2740	2970	3260	3660	4750	5170	5770
000	170	65	130	162	323	647	970	1170	1740	1940	2840	3100	3370	3690	4150	5375	5850	6550
0000	200	76	152	190	380	760	1140	1375	2040	2240	3340	3650	3960	4340	4870	6325	6900	7700
250 000	225	86	172	214	428	857	1285	1550	2300	2520	3750	4100	4450	4880	5470	7125	7750	8650
300 000	250	95	190	238	475	950	1430	1720	2560	2800	4170	4550	4950	5425	6100	7900	8600	9625
350 000	280	106	213	266	532	1065	1600	1925	2860	3140	4670	5100	5550	6070	6825	8850	9650	10800
400 000	310	118	236	295	590	1180	1770	2130	3170	3480	5170	5650	6150	6720	7550	9800	10700	11950
450 000	340	129	258	323	647	1295	1940	2340	3480	3810	5670	6200	6750	7370	8300	10750	11700	13100
500 000	360	137	274	342	685	1370	2050	2480	3680	4040	6000	6550	7130	7800	8770	11400	12400	13850
600 000	400	152	304	380	760	1520	2280	2760	4100	4500	6680	7300	7920	8680	9750	12650	13800	15400
700 000	470	179	358	447	895	1790	2680	3240	4800	5270	7820	8570	9300	10200	11450	14850	16200	18100

SINGLE CONDUCTOR CABLES

B & S NO. AREA IN CIRCULAR MILS	CARRYING CAPACITY IN AMPERES DIRECT CURRENT: N. E. CODE INTERIOR CONDUCTORS, X TABLE A RUBBER INSULATION	N. E. CODE INTERIOR CONDUCTORS, X TABLE B OTHER INSULATION	XXX BASED UPON 30°C RISE & A MAXIMUM OF 3000 VOLTS PAPER INSULATION	K.V.A. WHICH MAY BE TRANSMITTED AT THREE PHASE AND THE FOLLOWING VOLTAGES OVER THREE PAPER INSULATED LEAD COVERED CABLES INSTALLED IN A FOUR DUCT LINE WITH 30° C RISE IN TEMPERATURE BASED UPON THE ASSUMPTION THAT ALL DUCTS CARRY LOADED CABLES AND UPON A NORMAL EARTH TEMPERATURE OF 20° C. FOR A 6 DUCT LINE THESE K.V.A. VALUES WOULD BE REDUCED TO APPROXIMATELY 88 PER CENT FOR AN 8 DUCT LINE TO 79 PER CENT FOR A 10 DUCT LINE TO 71 PER CENT; FOR A 12 DUCT LINE TO 63 PER CENT AND FOR A 16 DUCT LINE (4 WIDE AND 4 HIGH) TO 60 PER CENT OF THE TABLE VALUES XXXX																
				220 VOLTS	440 VOLTS	550 VOLTS	1100 VOLTS	2200 VOLTS	3300 VOLTS	4000 VOLTS	6000 VOLTS	6600 VOLTS	10000 VOLTS	11000 VOLTS	12000 VOLTS	13200 VOLTS	15000 VOLTS	20000 VOLTS	22000 VOLTS	25000 VOLTS
14	15	20	24	9	18	23	46	92	137	165	245	270	400	437	475	520	585	758	826	925
12	20	25	30	11	23	28	57	114	171	206	306	337	500	547	595	650	732	948	1033	1155
10	25	30	40	15	30	38	76	152	228	275	408	450	667	730	792	868	975	1265	1378	1540
8	35	50	55	21	42	52	104	209	314	378	560	617	917	1010	1090	1195	1340	1740	1895	2120
7	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	50	70	75	28	57	71	142	284	428	515	765	842	1250	1270	1485	1630	1830	2370	2580	2890
5	55	80	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	70	90	95	36	72	90	181	362	540	653	970	1065	1585	1730	1880	2060	2320	3000	3270	3660
3	80	100	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	90	125	125	47	95	119	237	475	712	860	1275	1405	2085	2280	2480	2710	3050	3950	4300	4820
1	100	150	150	57	114	143	285	570	855	1030	1530	1685	2500	2715	2970	3260	3660	4740	5170	5780
0	125	200	170	65	130	162	323	647	970	1170	1740	1910	2830	3100	3370	3690	4150	5380	5850	6550
00	150	225	200	76	152	190	380	760	1140	1380	2040	2280	3330	3650	3960	4350	4880	6320	6880	7700
000	175	275	230	87	175	219	437	875	1310	1580	2350	2620	3840	4200	4550	5000	5600	7270	7920	8860
0000	225	325	270	103	205	256	512	1025	1540	1860	2760	3030	4500	4920	5350	5850	6580	8530	9300	10400
250 000	—	—	300	114	228	285	570	1140	1710	2060	3070	3370	5000	5470	5950	6500	7320	9500	10350	11550
300 000	275	400	340	129	259	324	647	1295	1940	2340	3470	3820	5670	6200	6730	7380	8300	10750	11700	13200
350 000	—	—	380	144	289	362	723	1445	2170	2620	3880	4270	6330	6920	7520	8250	9260	12000	13100	14650
400 000	325	500	410	156	312	390	780	1560	2340	2820	4180	4600	6850	7480	8120	8900	10000	12950	14150	15800
450 000			450	172	343	428	855	1710	2560	3100	4600	5050	7500	8200	8900	9770	10900	14200	15500	17350
500 000	400	600	480	183	365	456	912	1825	2740	3300	4900	5400	8000	8750	9500	10400	11700	15200	16550	18500
600 000	450	680	550	209	418	522	1045	2090	3140	3790	5620	6180	9170	10000	10900	11950	13400	17400	18950	21200
700 000	500	760	610	232	464	580	1160	2320	3480	4200	6220	6850	10150	11100	12100	13250	14850	19300	21000	23500
800 000	550	840	670	255	510	638	1275	2550	3820	4600	6850	7520	11150	12200	13250	14550	16350	21200	23100	25800
900 000	600	920	720	274	548	685	1370	2740	4100	4950	7350	8100	12000	13150	14250	15650	17550	22700	24800	27700
1 000 000	650	1000	780	297	594	742	1480	2960	4450	5370	7950	8750	13000	14200	15450	16950	19000	24650	26800	30100
1 100 000	690	1080	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 200 000	730	1150	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 250 000	—	—	900	342	685	855	1710	3420	5130	6200	9200	10100	15000	16400	17800	19550	21900	28400	31000	34700
1 300 000	770	1220	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 400 000	810	1290	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 500 000	850	1360	1030	392	785	980	1960	3920	5870	7100	10500	11550	17200	18800	20400	22400	25100	32600	35500	39700
1 600 000	890	1430	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1 750 000	—	—	1130	430	860	1075	2150	4300	6450	7770	11550	12700	18800	20600	22400	24500	27500	35700	39000	43600
1 900 000	1010	1610	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2 000 000	1050	1670	1260	480	960	1200	2400	4800	7200	8670	12850	14150	21000	23000	25000	27300	30700	39800	43300	48600

X For purposes of comparison these values are given for interior conductors.

XX For four conductor cables these ampere values would be reduced by 12.5 percent.

XXX For solid conductors these ampere ratings would be reduced by seven percent. For two conductor cables made up either round or flat, they would be reduced by 15 per cent. For two conductor concentric cables they would be reduced by 25 percent. They will also be reduced in the case of the larger conductors when used on alternating-current circuits on account of skin effect, unless special cables having non-conducting cores are used. These special cables should be used for 700 000 circ. mils and larger for 60 cycle and 1 000 000 circ. mils and larger for 25 cycle service.

XXXX For the higher voltage cables the kv-a values of the table have been reduced by one percent for each 2000 volts that the working pressure exceeds 3000 volts, that is by 11 percent for a 25 000 volt cable. For insulated aluminum conductors the safe carrying capacity (based upon 61 percent conductivity) is 79.3 percent of the above table values with the same kind of insulation. These kv-a values are based upon the current in columns headed by XX and XXX.

stranded conductor. The values for inductance, as determined by the fundamental formula, would thus tend to give values several per cent less than the actual when applied to three conductor cable calculations. On the other hand spiraling the conductors of three conductor cables tends to increase their reactance by several per cent. It may, therefore, be assumed that the use of the fundamental formula in the case of three conductor cables give results approximately correct. Skin effect on the larger cables will, however, tend to decrease the reactance slightly, particularly at 60 cycles.

INDUCTANCE, REACTANCE AND IMPEDANCE, AT 25 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE CONDUCTOR CABLES

INSULATION THICKNESS IN 64THS OF AN INCH **

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS *	3/64 BY 3/64 IND. M.H.	3/64 BY 3/64 REAC. OHMS	3/64 BY 3/64 IMP. OHMS	4/64 BY 4/64 IND. M.H.	4/64 BY 4/64 REAC. OHMS	4/64 BY 4/64 IMP. OHMS	5/64 BY 5/64 IND. M.H.	5/64 BY 5/64 REAC. OHMS	5/64 BY 5/64 IMP. OHMS	6/64 BY 6/64 IND. M.H.	6/64 BY 6/64 REAC. OHMS	6/64 BY 6/64 IMP. OHMS
500 000	.814	.116	.338	.127	.172	.349	.131	.175	.360	.136	.178	.370	.140	.182
450 000	.772	.129	.340	.128	.181	.351	.132	.184	.362	.137	.189	.373	.141	.191
400 000	.728	.145	.343	.129	.195	.354	.134	.197	.367	.138	.201	.377	.142	.204
350 000	.681	.166	.346	.130	.211	.357	.135	.214	.370	.140	.217	.380	.143	.220
300 000	.630	.194	.349	.132	.235	.361	.136	.237	.374	.141	.240	.386	.145	.244
250 000	.575	.233	.353	.133	.268	.366	.138	.271	.381	.144	.274	.394	.149	.277
0000	.528	.275	.357	.135	.308	.372	.140	.309	.387	.146	.313	.403	.152	.316
000	.470	.346	.362	.136	.373	.379	.143	.375	.397	.150	.378	.411	.155	.381
00	.418	.437	.369	.139	.460	.388	.146	.461	.406	.153	.464	.423	.160	.466
0	.373	.550	.377	.142	.569	.398	.150	.571	.417	.157	.572	.432	.163	.573
1	.332	.695	.384	.145	.711	.405	.152	.713	.429	.162	.715	.447	.168	.716
2	.292	.879	.393	.148	.893	.417	.157	.894	.441	.166	.896	.463	.174	.896
3	.260	1.11	.403	.152	1.12	.431	.162	1.12	.454	.171	1.12	.476	.180	1.12
4	.232	1.40	.413	.156	1.41	.442	.167	1.41	.469	.177	1.41	.494	.186	1.41
6	.184	2.21	.437	.165	2.22	.470	.177	2.22	.501	.189	2.22	.529	.200	2.22

AREA	DIAMETER	RESISTANCE	7/64 BY 7/64 IND. M.H.	7/64 BY 7/64 REAC. OHMS	7/64 BY 7/64 IMP. OHMS	8/64 BY 8/64 IND. M.H.	8/64 BY 8/64 REAC. OHMS	8/64 BY 8/64 IMP. OHMS	9/64 BY 9/64 IND. M.H.	9/64 BY 9/64 REAC. OHMS	9/64 BY 9/64 IMP. OHMS	10/64 BY 10/64 IND. M.H.	10/64 BY 10/64 REAC. OHMS	10/64 BY 10/64 IMP OHMS
500 000	.814	.116	.379	.143	.184	.389	.146	.186	.398	.150	.190	.407	.153	.192
450 000	.772	.129	.384	.145	.194	.393	.148	.195	.403	.152	.200	.411	.155	.202
400 000	.728	.145	.389	.147	.206	.396	.149	.208	.409	.154	.212	.417	.157	.230
350 000	.681	.166	.395	.149	.222	.402	.151	.224	.415	.157	.229	.423	.160	.231
300 000	.630	.194	.399	.150	.245	.409	.154	.246	.421	.158	.251	.431	.162	.254
250 000	.575	.233	.409	.154	.279	.419	.158	.282	.430	.162	.285	.442	.166	.286
0000	.528	.275	.415	.157	.318	.427	.161	.320	.441	.166	.323	.452	.170	.323
000	.470	.346	.429	.162	.383	.440	.166	.385	.455	.172	.388	.466	.176	.389
00	.418	.437	.439	.166	.467	.455	.171	.471	.469	.177	.473	.483	.182	.474
0	.373	.550	.453	.171	.578	.466	.176	.578	.485	.183	.580	.498	.188	.582
1	.332	.695	.466	.176	.718	.483	.182	.697	.501	.189	.720	.516	.195	.721
2	.292	.879	.483	.182	.900	.502	.189	.900	.521	.196	.902	.537	.202	.902
3	.260	1.11	.499	.188	1.13	.519	.195	1.13	.538	.203	1.13	.558	.211	1.13
4	.232	1.40	.518	.195	1.41	.538	.203	1.41	.558	.210	1.42	.577	.218	1.42
6	.184	2.21	.557	.210	2.22	.580	.219	2.22	.601	.226	2.22	.622	.234	2.22

AREA	DIAMETER	RESISTANCE	11/64 BY 11/64 IND. M.H.	11/64 BY 11/64 REAC. OHMS	11/64 BY 11/64 IMP. OHMS	12/64 BY 12/64 IND. M.H.	12/64 BY 12/64 REAC. OHMS	12/64 BY 12/64 IMP. OHMS	13/64 BY 13/64 IND. M.H.	13/64 BY 13/64 REAC. OHMS	13/64 BY 13/64 IMP. OHMS	14/64 BY 14/64 IND. M.H.	14/64 BY 14/64 REAC. OHMS	14/64 BY 14/64 IMP. OHMS
500 000	.814	.116	.417	.157	.195	.427	.161	.198	.434	.164	.202	.441	.166	.202
450 000	.772	.129	.423	.160	.204	.431	.162	.208	.439	.165	.211	.449	.170	.211
400 000	.728	.145	.429	.161	.216	.436	.164	.220	.446	.168	.222	.457	.172	.224
350 000	.681	.166	.436	.164	.235	.446	.168	.237	.453	.171	.240	.464	.175	.240
300 000	.630	.194	.444	.167	.256	.456	.172	.260	.461	.174	.262	.473	.178	.264
250 000	.575	.233	.454	.171	.289	.465	.175	.292	.475	.179	.295	.486	.183	.296
0000	.528	.275	.465	.175	.328	.476	.180	.330	.486	.183	.332	.498	.188	.334
000	.470	.346	.481	.181	.392	.493	.186	.395	.503	.190	.396	.516	.194	.398
00	.418	.437	.498	.188	.476	.510	.192	.479	.521	.196	.480	.535	.202	.482
0	.373	.550	.514	.194	.584	.528	.199	.586	.539	.203	.589	.554	.209	.590
1	.332	.695	.531	.200	.724	.546	.206	.725	.559	.211	.726	.573	.216	.728
2	.292	.879	.554	.209	.905	.570	.215	.906	.583	.220	.908	.598	.225	.910
3	.260	1.11	.574	.216	1.13	.591	.222	1.13	.606	.228	1.13	.618	.233	1.14
4	.232	1.40	.596	.224	1.42	.613	.231	1.42	.627	.236	1.42	.643	.242	1.42
6	.184	2.21	.643	.242	2.22	.661	.249	2.22	.678	.256	2.22	.696	.262	2.23

AREA	DIAMETER	RESISTANCE	16/64 BY 16/64 IND. M.H.	16/64 BY 16/64 REAC. OHMS	16/64 BY 16/64 IMP. OHMS	18/64 BY 18/64 IND. M.H.	18/64 BY 18/64 REAC. OHMS	18/64 BY 18/64 IMP. OHMS	20/64 BY 20/64 IND. M.H.	20/64 BY 20/64 REAC. OHMS	20/64 BY 20/64 IMP. OHMS	22/64 BY 22/64 IND. M.H.	22/64 BY 22/64 REAC. OHMS	22/64 BY 22/64 IMP. OHMS
500 000	.814	.116	.457	.172	.208	.474	.179	.212	.487	.183	.217	.501	.189	.222
450 000	.772	.129	.462	.174	.218	.481	.181	.224	.496	.187	.228	.509	.192	.232
400 000	.728	.145	.471	.178	.230	.487	.183	.235	.505	.190	.240	.519	.196	.244
350 000	.681	.166	.480	.181	.246	.496	.187	.252	.513	.193	.254	.529	.200	.260
300 000	.630	.194	.491	.185	.270	.511	.192	.274	.526	.198	.279	.541	.204	.282
250 000	.575	.233	.505	.190	.302	.524	.197	.306	.541	.204	.311	.557	.210	.314
0000	.528	.275	.517	.195	.338	.536	.202	.342	.556	.210	.348	.573	.216	.352
000	.470	.346	.536	.202	.403	.556	.209	.406	.575	.217	.410	.592	.223	.415
00	.418	.437	.552	.208	.486	.578	.218	.490	.599	.226	.494	.618	.233	.496
0	.373	.550	.575	.217	.592	.601	.226	.596	.621	.234	.599	.641	.242	.602
1	.332	.695	.598	.225	.732	.623	.235	.734	.645	.243	.737	.666	.251	.740
2	.292	.879	.623	.235	.912	.649	.245	.914	.674	.254	.917	.693	.261	.920
3	.260	1.11	.649	.245	1.14	.674	.254	1.14	.698	.262	1.14	.721	.272	1.14
4	.232	1.40	.673	.254	1.42	.701	.264	1.43	.725	.273	1.43	.746	.281	1.43
6	.184	2.21	.725	.273	2.22	.754	.284	2.23	.780	.294	2.23	.809	.305	2.23

*Resistance based upon 100 percent conductivity at 25 degrees C (77 degrees F), including two percent allowance for spiral of strands and two percent allowance for spiral of conductors. For a temperature of 65 degrees C (149 degrees F) these resistance values would be increased 15 percent.

**The inductance is in millihenries; the reactance and the impedance are in ohms.

The table values were derived from the equation $L = 0.08047 + 0.741 \, Log_{10} \frac{D}{R}$ where R is the radius of conductor, D the distance between centers of conductors expressed in the same terms as R, and L the inductance in millihenries per mile of each conductor. All values in the table are single-phase and based upon a single conductor one mile long.

CAPACITANCE OF THREE CONDUCTOR CABLES

Formulas for determining the approximate capacitance of three conductor cables are cumbersome. They give reasonably accurate results only in the case of a homogeneous dielectric and in cases where the conductors are small compared to the radius of the sheath. They give inaccurate results in cases of large conduc-

INDUCTANCE, REACTANCE AND IMPEDANCE, AT 60 CYCLES, PER MILE OF SINGLE CONDUCTOR FOR THREE CONDUCTOR CABLES

INSULATION THICKNESS IN 64THS OF AN INCH ★★

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	3/64 BY 3/64			4/64 BY 4/64			5/64 BY 5/64			6/64 BY 6/64		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS
500 000	.814	.116	.338	.0530	.128	.349	.0547	.129	.360	.0565	.129	.370	.0580	.130
450 000	.772	.129	.340	.0534	.140	.351	.0552	.140	.362	.0568	.141	.373	.0585	.142
400 000	.728	.145	.343	.0537	.155	.354	.0554	.155	.367	.0576	.155	.377	.0592	.157
350 000	.681	.166	.346	.0542	.175	.357	.0560	.176	.370	.0581	.176	.380	.0596	.177
300 000	.630	.194	.349	.0547	.204	.361	.0567	.204	.374	.0587	.205	.386	.0605	.207
250 000	.575	.233	.353	.0554	.240	.366	.0575	.240	.381	.0597	.240	.394	.0619	.242
0000	.528	.275	.357	.0560	.281	.372	.0585	.281	.387	.0607	.282	.403	.0633	.282
000	.470	.346	.362	.0567	.352	.379	.0595	.352	.397	.0623	.352	.411	.0645	.353
00	.418	.437	.369	.0579	.441	.388	.0609	.442	.406	.0637	.442	.423	.0665	.442
0	.373	.550	.377	.0592	.552	.398	.0625	.554	.417	.0653	.554	.432	.0677	.554
1	.332	.695	.384	.0603	.697	.405	.0635	.698	.429	.0673	.698	.447	.0700	.699
2	.292	.879	.393	.0617	.882	.417	.0655	.882	.441	.0691	.882	.463	.0727	.882
3	.260	1.11	.403	.0633	1.11	.431	.0675	1.11	.454	.0712	1.11	.476	.0746	1.11
4	.232	1.40	.413	.0648	1.40	.442	.0695	1.40	.469	.0736	1.40	.494	.0775	1.40
6	.184	2.21	.437	.0685	2.21	.470	.0737	2.21	.501	.0785	2.21	.529	.0830	2.21

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	7/64 BY 7/64			8/64 BY 8/64			9/64 BY 9/64			10/64 BY 10/64		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS
500 000	.814	.116	.379	.0595	.130	.389	.0610	.131	.398	.0625	.132	.407	.0640	.133
450 000	.772	.129	.384	.0602	.143	.393	.0617	.143	.403	.0634	.144	.411	.0645	.145
400 000	.728	.145	.389	.0610	.158	.396	.0622	.158	.409	.0642	.159	.417	.0655	.160
350 000	.681	.166	.395	.0620	.177	.402	.0630	.178	.415	.0652	.178	.423	.0664	.179
300 000	.630	.194	.399	.0626	.207	.409	.0642	.205	.421	.0660	.205	.431	.0675	.206
250 000	.575	.233	.409	.0642	.242	.419	.0658	.242	.430	.0675	.242	.442	.0693	.243
0000	.528	.275	.415	.0652	.283	.427	.0673	.283	.441	.0690	.284	.452	.0708	.285
000	.470	.346	.429	.0673	.353	.440	.0690	.353	.455	.0714	.354	.466	.0730	.355
00	.418	.437	.439	.0690	.443	.455	.0714	.443	.469	.0735	.443	.483	.0758	.444
0	.373	.550	.453	.0712	.554	.466	.0731	.554	.485	.0760	.555	.498	.0780	.556
1	.332	.695	.466	.0732	.698	.483	.0757	.697	.501	.0785	.699	.516	.0810	.700
2	.292	.879	.483	.0758	.882	.502	.0787	.882	.521	.0816	.833	.537	.0843	.883
3	.260	1.11	.499	.0782	1.11	.519	.0814	1.11	.538	.0845	1.11	.558	.0875	1.11
4	.232	1.40	.518	.0813	1.40	.538	.0845	1.40	.558	.0875	1.40	.577	.0905	1.40
6	.184	2.21	.557	.0873	2.21	.580	.0910	2.21	.601	.0943	2.21	.622	.0975	2.21

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	11/64 BY 11/64			12/64 BY 12/64			13/64 BY 13/64			14/64 BY 14/64		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS
500 000	.814	.116	.417	.0655	.133	.427	.0670	.133	.434	.0681	.134	.441	.0691	.135
450 000	.772	.129	.423	.0665	.145	.431	.0675	.145	.439	.0690	.146	.449	.0705	.147
400 000	.728	.145	.429	.0673	.160	.436	.0683	.160	.446	.0700	.161	.457	.0717	.162
350 000	.681	.166	.436	.0685	.180	.446	.0700	.180	.453	.0710	.180	.464	.0729	.181
300 000	.630	.194	.444	.0697	.206	.456	.0715	.206	.461	.0722	.207	.473	.0742	.208
250 000	.575	.233	.454	.0712	.244	.465	.0730	.244	.475	.0745	.245	.486	.0762	.245
0000	.528	.275	.465	.0730	.285	.476	.0745	.285	.486	.0760	.286	.498	.0782	.287
000	.470	.346	.481	.0755	.355	.493	.0775	.355	.503	.0790	.355	.516	.0810	.356
00	.418	.437	.498	.0780	.445	.510	.0800	.445	.521	.0816	.445	.535	.0840	.446
0	.373	.550	.514	.0805	.556	.528	.0828	.556	.539	.0845	.556	.554	.0870	.557
1	.332	.695	.531	.0830	.700	.546	.0855	.700	.559	.0877	.700	.573	.0900	.700
2	.292	.879	.554	.0870	.882	.570	.0895	.882	.583	.0915	.883	.598	.0938	.884
3	.260	1.11	.574	.0900	1.11	.591	.0927	1.11	.606	.0950	1.11	.618	.0970	1.11
4	.232	1.40	.596	.0935	1.40	.613	.0962	1.40	.627	.0983	1.40	.643	.1010	1.41
6	.184	2.21	.643	.1010	2.21	.661	.1037	2.21	.678	.1063	2.21	.696	.1090	2.21

AREA IN CIRCULAR MILS B & S NO.	DIAMETER IN INCHES	RESISTANCE PER MILE IN OHMS ★	16/64 BY 16/64			18/64 BY 18/64			20/64 BY 20/64			22/64 BY 22/64		
			IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS	IND. M.H.	REAC. OHMS	IMP. OHMS
500 000	.814	.116	.457	.0717	.136	.474	.0744	.138	.487	.0764	.140	.501	.0785	.141
450 000	.772	.129	.462	.0725	.148	.481	.0754	.150	.496	.0778	.151	.509	.0800	.152
400 000	.728	.145	.471	.0738	.163	.487	.0764	.164	.505	.0792	.165	.519	.0815	.166
350 000	.681	.166	.480	.0753	.182	.496	.0778	.183	.513	.0805	.185	.529	.0830	.186
300 000	.630	.194	.491	.0770	.208	.511	.0802	.210	.526	.0825	.211	.541	.0848	.212
250 000	.575	.233	.505	.0792	.246	.524	.0822	.247	.541	.0848	.248	.557	.0875	.249
0000	.528	.275	.517	.0810	.287	.536	.0840	.288	.556	.0870	.289	.573	.0900	.290
000	.470	.346	.536	.0840	.357	.556	.0870	.357	.575	.0905	.358	.592	.0930	.360
00	.418	.437	.552	.0865	.446	.578	.0907	.446	.599	.0940	.447	.618	.0970	.448
0	.373	.550	.575	.0902	.558	.601	.0942	.558	.621	.0972	.558	.641	.1005	.559
1	.332	.695	.598	.0938	.700	.623	.0980	.700	.645	.1010	.701	.666	.1045	.702
2	.292	.879	.623	.0978	.884	.649	.1017	.884	.674	.1060	.885	.693	.1085	.886
3	.260	1.11	.649	.1018	1.11	.674	.1060	1.11	.698	.1095	1.11	.721	.1130	1.12
4	.232	1.40	.673	.1055	1.41	.701	.1100	1.41	.725	.1138	1.41	.746	.1170	1.41
6	.184	2.21	.725	.1135	2.22	.754	.1180	2.22	.780	.1225	2.22	.809	.1270	2.22

* Resistance based upon 100 percent conductivity at 25 degrees C (77 degrees F), including two percent allowance for spiral of strands and two percent allowance for spiral of conductors. For a temperature of 65 degrees C (149 degrees F) these resistance values would be increased 15 percent.

** The inductance is in millihenries; the reactance and the impedance are in ohms.

The table values were derived from the equation $L = 0.08047 + 0.741 \, Log_{10} \frac{D}{R}$ where R is the radius of conductor, D the distance between centers of conductors expressed in the same terms as R, and L the inductance in millihenries per mile of each conductor. All values in the table are single-phase and based upon a single conductor one mile long.

tors closely spaced. Figure 82* illustrates the various capacitances of a three conductor cable. Formulas taken from Russell's "Alternating Currents" have been combined and converted to common logarithms and

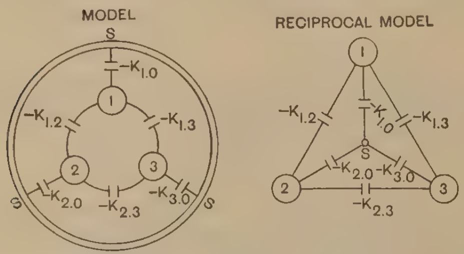


FIG. 82.—Representation of capacitances of a symmetrical three-phase cable.

are given below. They were derived by the method of images and on the assumption that the conductors are round and symmetrically spaced with respect to the axis of the sheath.

$$C_1 = \frac{1}{13.82 \log_{10} \dfrac{R^6 - d^6}{3\, R^3\, d^2\, r}} + \frac{1}{6.91 \log_{10}\left(\dfrac{1.73d}{r} \times \dfrac{R^2 - d^2}{(R^4 + R^2d^2 + d^4)^{1/2}}\right)} \times 0.179 \times K. \quad (70)$$

$$C_{12} = \frac{1}{13.82 \log_{10} \dfrac{R^6 - d^6}{3\, R^3\, d^2\, r}} - \frac{1}{13.82 \log_{10}\left(\dfrac{1.73d}{r} \times \dfrac{R^2 - d^2}{(R^4 + R^2\, d^2 + d^4)^{1/2}}\right)} \times 0.179 \times K. \quad (71)$$

Where,

R = inside radius of sheath in centimeters (Fig. 83).
r = radius of conductor in centimeters.
d = distance between axis of conductor and axis of sheath in centimeters.
K = the dielectric constant. For impregnated paper insulation it varies between 3 and 4; for varnished cambric insulation it varies between 4 and 6; for rubber insulation it varies between 4 and 9.
C_1 = capacitance in microfarads per mile between one conductor and the other two conductors plus the sheath.
C_{1-2} = mutual capacitance in microfarads per mile between any two conductors. The capacitance to neutral is twice this value.
C_{12} is used in determining the capacitance for various combinations or arrangements as explained below.

CAPACITANCE AND SUSCEPTANCE

The accompanying table contains values for capacitance and susceptance of three conductor paper insulated cable for the various sizes of conductors and thicknesses of insulation indicated. All values are based upon a value for K of 3.5 and, as indicated, a thickness of insulation for the jacket the same as that surrounding each conductor. The values were calculated by equations (70) and (71).

The susceptance values given for 25 and 60 cycles are to neutral. In calculating the voltage regulation of circuits, it is general practice to calcuate the regulation on the basis of one conductor to neutral. The susceptance between two of the conductors would be half the table values to neutral. The values for susceptance were calculated from the equation,

Susceptance to neutral in micromhos = $2\pi fC$.

Thus No. 0 three conductor cable with 7/64 and 7/64 insulation has a capacitance between conductors of 0.195 microfarads (0.39 microfarads to neutral). The susceptance to neutral at 60 cycles therefore is, $2\pi 60 \times 0.39 = 147$ microfarads, as indicated by the table.

INTER-RELATION OF CAPACITANCE OF THREE CONDUCTOR CABLES

The following equations for determining the effective capacitance for various arrangements of the three conductors and the sheath are given in Russell's "Alternating Currents."

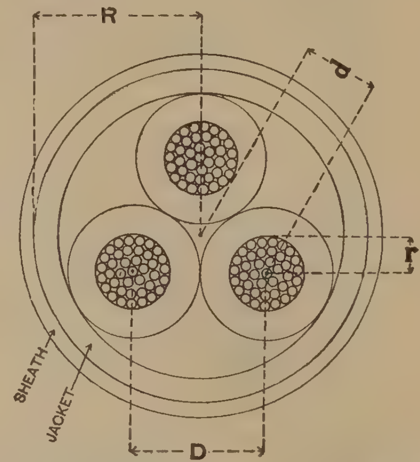


FIG. 83.—Dimensions of a symmetrical three-phase cable.

Capacitance between 1 and 2 = $\frac{1}{2}(C_1 - C_{12})$ (72)

Capacitance between 1 and 2, 3 = $\frac{2}{3}(C_1 - C_{12})$ (73)

Capacitance between 1 and S (2 and 3 insulated) =
$$\frac{(C_1 - C_{12})(C_1 + 2C_{12})}{C_1 + C_{12}} \quad (74)$$

Capacitance between 1 and S, 2(3 insulated) =
$$\frac{(C_1 - C_{12})(C_1 + C_{12})}{C_1} \quad (75)$$

Capacitance between 1 and S, 2, 3 = C_1 (76)

Capacitance between S and 1, 2, (3 insulated) =
$$\frac{2(C_1 - C_{12})(C_1 + 2C_{12})}{C_1} \quad (77)$$

Capacitance between 1, S and 2, 3 = $2\,(C_1 + C_{12})$ (78)

Capacitance between S and 1, 2, 3 = $3\,(C_1 + 2C_{12})$ (79)

C_1 (76) may be measured in the ordinary way, by reading the throw of a mirror galvanometer and comparing with the throw given by a standard condenser. A further measurement of (78) or (79) will give a simple equation to find C_{12}. For instance, if measurements were taken of (78) and (79) and were found to be:

$2C_1 + 2C_{12} = 0.410$ mf. per mile (78)
And $3C_1 + 6C_{12} = 0.450$ mf. per mile (79)
Therefore $C_1 = 0.26$ mg. per mile
$C_{12} = -0.055$ mg. per mile

* Reproduced from ALEXANDER RUSSELL "Alternating Currents."

CAPACITANCE AND SUSCEPTANCE PER MILE OF THREE CONDUCTOR PAPER INSULATED CABLES

INSULATION THICKNESS IN 64THS OF AN INCH

3/64 BY 3/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.680	-.217	.448	141	337
450 000	.667	-.197	.432	136	325
400 000	.657	-.194	.425	133	320
350 000	.640	-.189	.414	130	313
300 000	.606	-.176	.391	123	294
250 000	.590	-.171	.380	120	286
0000	.570	-.160	.365	111	265
000	.535	-.147	.341	107	257
00	.513	-.140	.327	103	246
0	.494	-.123	.308	97	232
1	.462	-.119	.290	91	219
2	.420	-.107	.263	83	198
3	.402	-.101	.251	79	189
4	.378	-.100	.239	75	180
6	.342	-.081	.211	66	159

4/64 BY 4/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.613	-.175	.394	124	297
450 000	.590	-.169	.379	119	286
400 000	.570	-.159	.364	114	274
350 000	.560	-.158	.359	113	270
300 000	.545	-.153	.349	110	263
250 000	.518	-.142	.330	104	249
0000	.500	-.134	.317	100	239
000	.475	-.125	.300	94	226
00	.447	-.116	.281	88	212
0	.422	-.107	.264	83	199
1	.398	-.099	.248	78	187
2	.373	-.091	.232	73	175
3	.352	-.084	.218	69	165
4	.330	-.077	.203	64	153
6	.301	-.063	.182	57	137

5/64 BY 5/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.555	-.154	.354	111	267
450 000	.538	-.149	.343	108	259
400 000	.517	-.142	.329	103	248
350 000	.506	-.138	.322	101	242
300 000	.490	-.131	.310	97	234
250 000	.468	-.125	.296	93	223
0000	.445	-.115	.280	88	211
000	.420	-.107	.262	82	198
00	.398	-.101	.249	78	187
0	.374	-.090	.232	73	175
1	.356	-.086	.221	69	167
2	.332	-.077	.203	64	153
3	.314	-.072	.193	61	145
4	.295	-.066	.180	57	136
6	.264	-.056	.160	50	121

6/64 BY 6/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.505	-.137	.321	101	242
450 000	.488	-.130	.309	97	233
400 000	.475	-.125	.300	94	226
350 000	.460	-.119	.289	91	218
300 000	.446	-.116	.281	88	212
250 000	.427	-.109	.268	84	202
0000	.407	-.103	.255	80	192
000	.384	-.095	.239	75	180
00	.364	-.088	.226	71	170
0	.342	-.081	.211	66	159
1	.323	-.074	.198	62	149
2	.305	-.070	.187	59	141
3	.284	-.062	.173	54	131
4	.270	-.059	.164	52	124
6	.239	-.050	.144	45	108

7/64 BY 7/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.468	-.124	.296	93	224
450 000	.454	-.119	.286	90	216
400 000	.442	-.116	.279	88	210
350 000	.426	-.108	.267	84	201
300 000	.415	-.105	.260	82	196
250 000	.400	-.101	.250	79	188
0000	.380	-.094	.237	75	178
000	.358	-.086	.222	70	168
00	.336	-.080	.208	65	157
0	.317	-.073	.195	61	147
1	.299	-.068	.183	58	138
2	.279	-.062	.170	54	128
3	.264	-.056	.160	50	121
4	.250	-.053	.151	47	114
6	.221	-.045	.133	42	100

8/64 BY 8/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.435	-.115	.275	86	207
450 000	.427	-.107	.267	84	201
400 000	.415	-.105	.260	82	196
350 000	.398	-.099	.248	78	187
300 000	.390	-.096	.243	76	183
250 000	.370	-.089	.229	72	173
0000	.354	-.085	.220	69	166
000	.332	-.079	.205	64	155
00	.313	-.071	.192	60	145
0	.293	-.065	.179	56	135
1	.280	-.061	.170	54	128
2	.264	-.056	.160	50	121
3	.248	-.052	.150	47	113
4	.233	-.048	.140	44	106
6	.209	-.041	.125	39	94

9/64 BY 9/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.410	-.104	.257	81	193
450 000	.405	-.103	.254	79	191
400 000	.392	-.099	.245	77	184
350 000	.380	-.093	.236	74	178
300 000	.365	-.089	.227	71	171
250 000	.352	-.087	.219	69	165
0000	.334	-.076	.205	64	155
000	.315	-.073	.194	61	146
00	.295	-.067	.181	57	136
0	.279	-.061	.170	54	128
1	.261	-.056	.158	50	119
2	.247	-.052	.150	47	113
3	.232	-.048	.140	44	106
4	.221	-.045	.133	42	100
6	.198	-.037	.117	37	88

10/64 BY 10/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.392	-.097	.244	77	184
450 000	.380	-.093	.236	74	178
400 000	.368	-.090	.229	72	173
350 000	.358	-.087	.222	70	167
300 000	.348	-.081	.215	68	162
250 000	.332	-.078	.205	65	155
0000	.316	-.073	.194	61	146
000	.296	-.066	.181	57	136
00	.278	-.061	.169	53	127
0	.263	-.056	.159	50	120
1	.247	-.055	.151	47	114
2	.233	-.048	.140	44	106
3	.222	-.044	.133	42	100
4	.210	-.041	.125	39	94
6	.188	-.036	.112	35	85

11/64 BY 11/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.371	-.089	.230	72	173
450 000	.364	-.087	.225	71	170
400 000	.356	-.085	.220	69	166
350 000	.340	-.080	.210	66	158
300 000	.329	-.078	.203	64	153
250 000	.316	-.072	.199	63	150
0000	.302	-.069	.185	58	140
000	.282	-.061	.171	54	129
00	.267	-.058	.162	51	122
0	.250	-.053	.151	48	114
1	.237	-.050	.143	45	108
2	.222	-.045	.133	42	100
3	.212	-.042	.127	40	96
4	.201	-.039	.120	38	91
6	.181	-.033	.107	34	81

12/64 BY 12/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.355	-.085	.220	69	166
450 000	.352	-.085	.218	68	164
400 000	.338	-.080	.209	66	157
350 000	.328	-.077	.202	63	152
300 000	.313	-.071	.192	60	145
250 000	. 98	-.068	.183	58	138
0000	.235	-.067	.176	55	133
000	.271	-.060	.165	52	124
00	.255	-.054	.154	48	116
0	.241	-.050	.145	46	109
1	.228	-.047	.137	43	103
2	.216	-.044	.130	41	98
3	.204	-.039	.121	38	91
4	.192	-.037	.114	36	86
6	.174	-.031	.102	32	77

13/64 BY 13/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.343	-.082	.212	67	160
450 000	.332	-.078	.205	64	155
400 000	.326	-.076	.201	63	152
350 000	.317	-.073	.195	61	147
300 000	.303	-.069	.186	59	140
250 000	.288	-.064	.176	55	133
0000	.278	-.061	.169	53	127
000	.261	-.056	.158	50	119
00	.247	-.052	.150	47	113
0	.233	-.048	.140	44	106
1	.220	-.044	.132	42	100
2	.208	-.041	.124	39	94
3	.195	-.037	.116	36	88
4	.186	-.034	.110	35	83
6	.168	-.030	.099	31	75

14/64 BY 14/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.329	-.078	.203	64	153
450 000	.321	-.075	.198	62	149
400 000	.310	-.071	.190	60	143
350 000	.300	-.068	.184	58	139
300 000	.290	-.065	.177	56	133
250 000	.276	-.061	.168	53	127
0000	.264	-.056	.160	50	121
000	.251	-.053	.152	48	115
00	.237	-.048	.142	45	107
0	.222	-.044	.133	42	100
1	.212	-.042	.127	40	96
2	.199	-.039	.118	37	89
3	.190	-.036	.113	36	85
4	.180	-.033	.106	33	80
6	.163	-.029	.096	30	73

16/64 BY 16/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.308	-.071	.189	59	143
450 000	.302	-.069	.185	58	140
400 000	.292	-.066	.179	56	135
350 000	.282	-.061	.171	54	129
300 000	.271	-.059	.165	52	125
250 000	.260	-.055	.157	49	118
0000	.248	-.052	.150	47	113
000	.234	-.048	.141	44	106
00	.222	-.044	.133	42	100
0	.210	-.041	.125	39	94
1	.198	-.038	.118	37	89
2	.190	-.036	.113	36	86
3	.179	-.034	.107	34	81
4	.170	-.030	.100	32	76
6	.154	-.025	.089	28	67

18/64 BY 18/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.288	-.065	.176	55	133
450 000	.282	-.062	.172	54	130
400 000	.276	-.060	.168	53	127
350 000	.266	-.057	.161	51	121
300 000	.256	-.054	.155	49	117
250 000	.244	-.051	.147	46	111
0000	.233	-.049	.141	44	106
000	.221	-.044	.132	42	100
00	.209	-.041	.125	39	94
0	.199	-.038	.118	37	89
1	.188	-.035	.111	35	84
2	.179	-.032	.105	33	79
3	.171	-.031	.101	32	76
4	.162	-.027	.094	30	71
6	.147	-.024	.085	27	64

20/64 BY 20/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.276	-.061	.168	53	127
450 000	.269	-.058	.163	51	123
400 000	.260	-.055	.157	50	118
350 000	.252	-.053	.152	48	115
300 000	.242	-.050	.146	46	110
250 000	.231	-.048	.139	44	105
0000	.222	-.044	.133	42	100
000	.211	-.041	.126	40	95
00	.199	-.038	.118	37	89
0	.188	-.036	.112	35	85
1	.181	-.034	.107	33	81
2	.170	-.030	.100	32	76
3	.162	-.028	.095	30	72
4	.154	-.026	.090	28	68
6	.141	-.023	.082	26	62

22/64 BY 22/64

AREA IN CIRCULAR MILS / B & S NO.	CAPACITANCE			SUSCEPTANCE TO NEUTRAL	
	C_1	C_{12}	$C_{1\&2}$	25 CYCLES	60 CYCLES
500 000	.263	-.057	.160	50	121
450 000	.255	-.054	.154	48	116
400 000	.249	-.053	.151	47	113
350 000	.240	-.049	.144	45	108
300 000	.232	-.047	.139	44	105
250 000	.222	-.044	.133	42	100
0000	.211	-.041	.126	40	96
000	.200	-.038	.119	38	90
00	.191	-.036	.113	36	85
0	.180	-.030	.105	33	79
1	.172	-.030	.101	32	76
2	.163	-.029	.096	30	73
3	.155	-.026	.090	28	68
4	.148	-.025	.086	27	65
6	.136	-.021	.078	25	59

Capacitance—The values in table for capacitance were derived by formulas in Alexander Russel's "Alternating Currents." These values are as follows:—C_1 values are the capacitance in microfarads per mile between one conductor and the other two conductors plus sheath. C_{1-2} values are the mutual capacitance in microfarads per mile between any two conductors. The capacitance to neutral is twice these values. C_{12} values per mile are used in the application of Russel's formulas for determining the capacitance corresponding to various arrangements of the three conductors and the sheath.

The Charging Current in amperes per mile for each conductor to neutral = susceptance in micromhos to neutral (taken from Table) × volts to neutral × 10^{-6}.

Dielectric Constant—All of the table values are based upon a value for the dielectric constant K of 3.5. For all other values of K the table values will change in direct proportion. Values for K will usually be found between the following limits; for impregnated paper 3.0 to 4.0; for varnished cambric 4.0 to 6.0 and for rubber 4.0 to 9.0.

Numerical Examples.—From the table for a 250,000 circ. mil, three conductor cable having a band of insulation surrounding each conductor of 16⁄64 in. and an insulation jacket surrounding all three conductors of the same thickness, the following values are obtained:

C_1 = 0.260 mf. per mile
C_{12} = −0.055 mf. per mile

Then, in the order in which the capacitance increases,

Capacitance between 1 and 2 = 0.157 mf. per mile (72)
Capacitance between 1 and 2, 3 = 0.210 mf. per mile (73)
Capacitance between 1 and S (2 and 3 insulated) = 0.230 mg. per mile (74)
Capacitance between 1 and S, 2 (3 insulated) = 0.248 mf. per mile (75)
Capacitance between 1 and S, 2, 3 = 0.260 mg. per mile (76)
Capacitance between S and 1, 2 (3 insulated) = 0.363 mf. per mile (77)
Capacitance between 1, S and 2, 3 = 0.410 mg. per mile (78)
Capacitance between S and 1, 2, 3 = 0.450 mf. per mile (79)

THREE-PHASE CHARGING KV.-A. PER MILE OF THREE-PHASE CIRCUIT OF THREE CONDUCTOR PAPER INSULATED CABLES

25 CYCLES

CHARGING KV-A PER MILE (EXPRESSED IN KV-A 3 PHASE) FOR PAPER INSULATED THREE CONDUCTOR CABLES BASED UPON A VALUE FOR 'K' OF 3.5 AND UPON A THICKNESS OF INSULATION SURROUNDING THE CONDUCTORS AND OF THE JACKET INDICATED.

AREA IN CIRCULAR MILS / B & S NO.	220 VOLTS 4/64	440 VOLTS 4/64	550 VOLTS 4/64	1100 VOLTS 5/64	2200 VOLTS 6/64	4400 VOLTS 8/64	6000 VOLTS 10/64	6000 VOLTS 14/64	6600 VOLTS 10/64	6600 VOLTS 14/64	6900 VOLTS 10/64
500 000	.00600	.0240	.0376	.134	.488	1.66	2.76	2.26	3.35	2.79	3.66
450 000	.00575	.0230	.0360	.131	.469	1.62	2.66	2.22	3.22	2.70	3.52
400 000	.00550	.0220	.0346	.125	.455	1.58	2.58	2.15	3.13	2.61	3.42
350 000	.00545	.0218	.0342	.122	.440	1.51	2.51	2.08	3.04	2.52	3.33
300 000	.00532	.0213	.0333	.117	.425	1.47	2.44	2.01	2.96	2.44	3.23
250 000	.00502	.0201	.0315	.113	.406	1.39	2.33	1.90	2.83	2.31	3.09
0000	.00483	.0193	.0303	.106	.387	1.33	2.19	1.79	2.65	2.18	2.90
000	.00454	.0182	.0285	.099	.363	1.24	2.04	1.72	2.48	2.09	2.71
00	.00424	.0170	.0266	.094	.343	1.16	1.90	1.61	2.31	1.96	2.52
0	.00400	.0160	.0250	.0883	.319	1.08	1.79	1.51	2.18	1.83	2.37
1	.00376	.0151	.0236	.0836	.300	1.04	1.68	1.43	2.05	1.74	2.23
2	.00352	.0141	.0221	.0775	.286	.965	1.58	1.33	1.92	1.61	2.09
3	.00333	.0133	.0209	.0740	.261	.908	1.51	1.29	1.83	1.57	2.00
4	.00309	.0124	.0194	.0690	.252	.850	1.40	1.18	1.70	1.44	1.85
6	.00275	.0110	.0173	.0605	.218	.755	1.26	1.08	1.52	1.31	1.66

25 CYCLES

	10,000 VOLTS 12/64	11000 VOLTS 12/64	11000 VOLTS 14/64	13,200 VOLTS 12/64	13,200 VOLTS 16/64	16,500 VOLTS 14/64	20,000 VOLTS 16/64	20,000 VOLTS 18/64	22,000 VOLTS 18/64	25000 VOLTS 18/64	25000 VOLTS 20/64
500 000	6.93	8.35	7.77	12.00	10.25	17.35	23.6	22.0	26.6	34.5	33.3
450 000	6.83	8.23	7.50	11.80	10.10	16.80	23.3	21.6	26.1	33.8	32.0
400 000	6.62	7.98	7.26	11.50	9.75	16.25	22.4	21.2	25.6	33.2	31.4
350 000	6.33	7.62	7.02	10.95	9.40	15.75	21.6	20.4	24.6	32.0	30.1
300 000	6.02	7.27	6.78	10.45	9.05	15.20	20.8	19.6	23.7	30.7	28.8
250 000	5.82	7.02	6.42	10.10	8.52	14.40	19.6	18.4	22.2	28.8	27.6
0000	5.53	6.66	6.05	9.56	8.17	13.55	18.8	17.6	21.3	27.6	26.4
000	5.23	6.30	5.82	9.05	7.65	13.05	17.6	16.8	20.3	26.3	25.1
00	4.82	5.80	5.45	8.36	7.30	12.25	16.8	15.6	18.8	24.4	23.2
0	4.62	5.57	5.09	8.00	6.78	11.40	15.6	14.8	17.8	23.2	22.0
1	4.32	5.21	4.84	7.48	6.43	10.85	14.8	14.0	16.9	21.9	20.7
2	4.12	4.97	4.48	7.13	6.26	10.05	14.4	13.2	15.9	20.7	20.1
3	3.82	4.60	4.36	6.60	5.92	9.78	13.6	12.8	15.5	20.1	18.8
4	3.62	4.36	4.00	6.27	5.57	8.95	12.8	12.0	14.5	18.8	17.6
6	3.22	3.87	3.63	5.57	4.87	8.15	11.2	10.8	13.1	16.9	16.3

60 CYCLES

	220 VOLTS 4/64	440 VOLTS 4/64	550 VOLTS 4/64	1100 VOLTS 5/64	2200 VOLTS 6/64	4400 VOLTS 8/64	6000 VOLTS 10/64	6000 VOLTS 14/64	6600 VOLTS 10/64	6600 VOLTS 14/64	6900 VOLTS 10/64
500 000	.0143	.0574	.0900	.323	1.17	4.00	6.58	5.49	8.00	6.65	8.73
450 000	.0138	.0554	.0858	.313	1.13	3.88	6.40	5.33	7.75	6.48	8.46
400 000	.0132	.0530	.0830	.301	1.09	3.79	6.20	5.13	7.53	6.22	8.22
350 000	.0131	.0523	.0818	.292	1.05	3.61	5.98	4.98	7.25	6.07	7.93
300 000	.0127	.0510	.0798	.283	1.02	3.54	5.80	4.78	7.05	5.80	7.70
250 000	.0120	.0483	.0755	.270	.975	3.35	5.55	4.56	6.75	5.52	7.37
0000	.0115	.0463	.0725	.255	.925	3.22	5.24	4.33	6.35	5.26	6.93
000	.0109	.0437	.0685	.240	.870	3.00	4.88	4.12	5.92	5.00	6.47
00	.0102	.0410	.0643	.226	.820	2.80	4.55	3.84	5.52	4.65	6.03
0	.0096	.0385	.0602	.212	.768	2.61	4.30	3.59	5.22	4.35	5.70
1	.0090	.0362	.0566	.202	.720	2.48	4.08	3.44	4.95	4.17	5.42
2	.0084	.0339	.0530	.185	.680	2.34	3.80	3.19	4.60	3.87	5.04
3	.0080	.0320	.0500	.176	.632	2.18	3.59	3.05	4.35	3.70	4.75
4	.0074	.0296	.0465	.165	.600	2.05	3.37	2.87	4.08	3.48	4.46
6	.0066	.0265	.0415	.147	.522	1.82	3.05	2.62	3.70	3.17	4.05

60 CYCLES

	10,000 VOLTS 12/64	11,000 VOLTS 12/64	11,000 VOLTS 14/64	13,200 VOLTS 12/64	13,200 VOLTS 16/64	16,500 VOLTS 14/64	20,000 VOLTS 16/64	20,000 VOLTS 18/64	22,000 VOLTS 18/64	25000 VOLTS 18/64	25000 VOLTS 20/64
500 000	16.7	20.1	18.5	28.9	24.9	41.5	57.3	53.3	64.2	83.3	79.5
450 000	16.5	19.8	18.1	28.5	24.4	40.3	56.0	52.0	62.7	81.5	77.0
400 000	15.8	19.0	17.3	27.2	23.5	38.8	54.0	50.9	61.3	79.5	74.0
350 000	15.3	18.4	16.8	26.4	22.4	37.6	51.6	48.5	58.3	75.8	72.2
300 000	14.6	17.6	16.1	25.2	21.8	36.0	50.0	46.8	56.5	73.3	69.0
250 000	13.9	16.7	15.4	24.0	20.5	34.5	47.3	44.3	53.6	69.5	65.7
0000	13.4	16.1	14.7	23.2	19.6	32.8	45.3	42.5	51.2	66.5	62.7
000	12.5	15.0	13.9	21.6	18.4	31.2	42.5	40.0	48.3	62.7	59.5
00	11.7	14.1	13.0	20.2	17.4	29.0	40.0	37.6	45.4	59.0	55.7
0	11.0	13.2	12.1	18.9	16.3	27.2	37.6	35.7	43.0	55.8	53.3
1	10.4	12.5	11.6	17.9	15.5	26.0	35.6	33.6	40.5	52.5	50.7
2	9.85	11.9	10.8	17.0	14.9	24.1	34.5	31.7	38.2	49.5	47.6
3	9.15	11.0	10.3	15.8	14.1	23.0	32.4	30.4	36.7	47.6	45.2
4	8.65	10.4	9.7	15.0	13.2	21.7	30.4	28.4	34.3	44.5	42.6
6	7.75	9.3	8.8	13.4	11.7	19.8	26.9	25.6	30.9	40.2	38.9

The values in the table are based upon a value for the dielectric constant K of 3.5. For all other values of K the table values will change in direct proportion. Values for K will usually be found between the following limits; for impregnated paper 3.0 to 4.0; for varnished cambric 4.0 to 6.0 and for rubber 4.0 to 9.0.

COMPARISON OF CALCULATED CAPACITANCE WITH TEST RESULTS

The difference between measured results of capacitance and the results calculated by the above formulas are given in Fig. 84. It will be seen that in all cases these calculated results are less than the corresponding test results, the discrepancy being greater as the conductor becomes larger and the separation less. The differences vary from zero to as much as 11 per cent for the largest cable, at the minimum spacing shown. The discrepancy is greatest with the minimum thickness of insulation. Since such cables would be used only for low-voltage service, the charging current would be small and consequently this error would probably be of little importance. For 6,600 volt cables the results by the formula would seem to be approximately 5 per cent too low.

The cause of the discrepancy between the formula and test results is as follows: In order to obtain a mathematical solution, Russel found it necessary to make certain approximations to the true physical conditions. Thus the resulting mathematical formula cannot give exact results. The approximation made by Russel is very close to the actual physical fact where the conductors are small compared with the insulation thickness, but it is not very close where the conductors are large compared with the insulation.

Recently two methods have been developed for the more accurate determination of capacitance of cables. D. M. Simons has developed a graphic methed for determining the so-called *geometric factor* by which corrections can be made to the standard formulae (see his paper "Cable Geometry and the Calculation of the Current Carrying Capacity," Journal, A. I. E. E., June, 1923). More recently H. B. Dwight* has developed a rigorous mathematical method of determining capacitance of conductors.

CHARGING KV.A.

The accompanying table contains values for charging current (expressed in kv.a., three phase) for three conductor paper insulated cables, both 25 and 60 cycles, based upon value for K of 3.5. For other values of K, the table values would vary in proportion. For other thicknesses of insulation, the kv.a. values would vary as the susceptance values corresponding to the thickness of insulation (See accompanying table). In some cases, such for instance, as grounded neutral systems, the thickness of insulation of the jacket may be less than that surrounding the conductors. In such cases it might be desirable to calculate the susceptance and charging current, if accurate results were desired. The values for charging current corresponding to two thicknesses of insulation are included for some of the commonly employed transmission voltages.

*"The Direct Method of Calculations of Capacitance of Conductors" by H. B. Dwight, Journal A. I. E. E., June, 1924.

These kv.a. values were calculated by using the values for susceptance in the table which, in turn, were derived from the capacitance in the same table obtained by formulae (70) and (71). Thus a 350,000 circ. mil cable with $^{10}\!/_{64}$ and $^{10}\!/_{64}$ paper insulation has a 60-cycle susceptance to neutral of 167 micromhos per mile. Since the charging current in amperes to neutral equals the susceptance to neutral $\times$ volts to neutral $\times\ 10^{-6}$ and assuming 6,600 volts, three phase between conductors, we have:

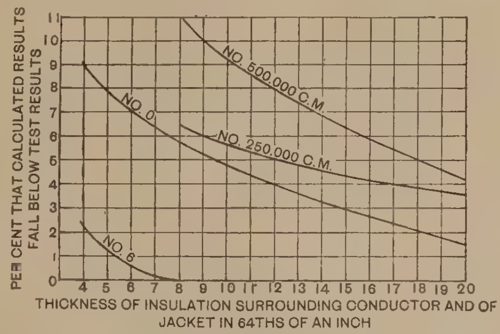


FIG. 84.—Comparison of calculated and measured capacitances. Tests made on three conductors paper insulated cables, $K = 3.5$

$$167 \times \frac{6600}{1.73} \times 10^{-6} = 0.637 \text{ amp. to neutral}$$

Charging kv.a. $= 0.637 \times 3{,}815 \times 3 = 7.25$ kv.a. as indicated in the table.

VALUES FOR K

The capacitance of any cable depends upon the dielectric constant of the insulating material and a dimension term or form factor. The dielectric constant should be determined from actual cables and not from samples of material. The usual range in value for K is given below.

	Value of K
Impregnated paper	3.0 to 4.0
Varnish cambric	4.0 to 6.0
Rubber	4.0 to 9.0

All values in the accompanying tables are based upon a value of K of 3.5. For all other values of K all table values will vary in the same proportion as their K values. The actual value of permittivity of most paper insulation runs about 10 per cent less than the value 3.5 which has been used in calculating the accompanying table values. The true alternating-current capacitance is always considerably lower than the capacitance measured with ballistic galvanometer.

Bibliography

The references on this subject are so numerous and current contributions are appearing so frequently that it is impractical here to present a complete list. Mr. D. M. Simons, Development Engineer of the Standard Underground Cable Co. in connection with his very valuable paper "Calculation of the Electrical Problem of Transmission by Underground Cables," in the Electric Journal of August, 1925, has compiled a very extensive Bibliography up to Jan. 1, 1925 embracing 283 references.

CHAPTER XVII

TRANSMISSION LINE INSULATORS

The present day porcelain insulator is an extremely high grade article and compares very favorably with any other product connected with electrical work. This cannot be said of the insulator through its twenty-five years of development, however, for at more than one period of this quarter century, electrical men had but little confidence in the ultimate outcome. In fact at times there were reasons to believe that the porcelain insulator, especially the suspension type, would never prove satisfactory. Fortunately in the last few years a rapidly crystallizing development has taken place, combining research work in the ceramics of porcelain with recently acquired knowledge of the manufacture and assembly of the different parts, with the result that today the porcelain insulator ranks as one of the most reliable elements of a transmission system.

Porcelain as a line insulator dates from a little before 1900 and during this early period neither the electrical nor mechanical requirements were very rigid. Porcelain work was considered an art that could be attained only through long experience in handling the clay and the unfired ware, and as a result not only the manufacture but the design of the insulator was turned over completely to the potteries. There was no real need for a refined product with the low voltage lines, the short spans and the small conductors; in fact the porcelain insulator was not especially needed at that time for the one piece glass insulator had been satisfactory. However, with the increase in voltage on various lines where larger insulators were required it soon became evident that glass could not be used. Electrically glass was satisfactory but for multipart insulators where mechanical strength was also a necessary factor, porcelain was soon accepted as the only possible material. With the suspension insulator in 1908 came the higher voltage lines, the pin type having practically limited transmission systems to 66 kv. Even at this time no particular refinement had taken place in the art as none had been required. The result was that when the low grade insulator was put to a real mechanical and electrical service test it not only did not come up to expectations but in some cases failed literally 100 per cent. The years from 1913 to 1915 saw a great change in the development of the insulator as a result of these wholesale failures. Electrical engineers of various large power companies, as well as the electrical manufacturers, realizing the situation, made an intensive study of the cause of these failures while at the same time the insulator manufacturers, through scientific analysis and experiment, refined the manufacture of the ware and the assembly of the units to a more reliable state. About 1920 the several causes of insulator failures had been definitely established and the requirements were fully known. Since that time the manufacturers, knowing the fundamental characteristics of the insulator, have given their attention to refinements in the grade of porcelain and in the assembly with the result that the product is of a very high grade electrically with very little room for improvement except in the direction of mechanical strength.

PIN TYPE INSULATORS

The first insulators to be used on any transmission line were of one piece glass, sometimes gaining insulation through the use of extraordinarily long wooden pins or by protecting the pins from the weather by shields or tubes of glass. Lines up to 44 kv. were insulated with one piece glass insulators that today have a rating of 15 kv. With the increase in voltage the multipart porcelain insulator made its appearance and gradually supplanted glass as a line insulator.

The early designs of pin type insulators were built up with a view toward including as much leakage surface as possible and with little or no regard for the electrostatic field or to the capacity of the various shells. Figure 85 is an illustration of one of the early designs of a four part 66 kv. insulator. At that time it was

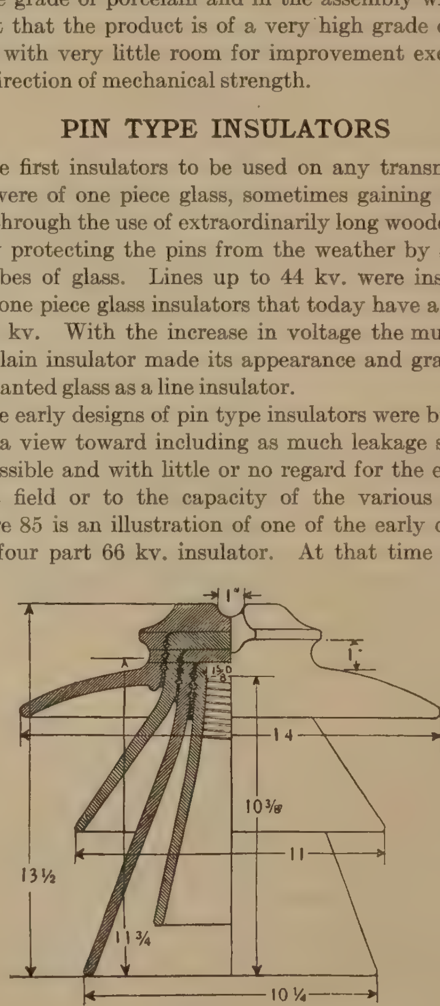


FIG. 85.

impossible to fire a thick section of porcelain and the large shells were thin and fragile. This coupled with the thick sections of cement and the corrugated cementing surfaces made an assembled unit that was not only weak mechanically, but also subject to expansion cracks. In addition the design was such that, although a great deal of leakage surface was attained, flashover values were low due to corona discharges between adjacent surfaces short circuiting the leakage surface.

In the design of an insulator the different items can not be made 100 per cent efficient but the whole must be a compromise. For instance it is necessary to sacrifice some flashover value to gain strength and to decrease weight. The insulator must be given mechanical strength up to the strength of pins and tie wires. Weight must be cut down for commercial reasons. Operating conditions must be considered next for the insulator will be required to work in both wet and dry weather. During the latter the surface of the porcelain will accumulate a coating of dirt and dust that must be removed by rain, and the shape must be designed with this in view. A comparison of the insulators in Fig. 61 and Fig. 62 indicates this essential point for while the greater part of the surface of the first insulator could never be cleaned, those of the second are so designed that both the upper and lower surfaces of each shed will be exposed to a driving rain.

Electrically the design shown in Fig. 86 is of maximum efficiency as will be noted in observing the following points:

1. The working surfaces conform to the electrostatic field while the surfaces of the rain shed conform to the equipotential surfaces.

2. The leakage surface of each shell is about equal, increasing gradually from head to center. This takes into consideration the fact that the larger lower surfaces, in becoming dirtier than the top, will equalize the leakage surface of each.

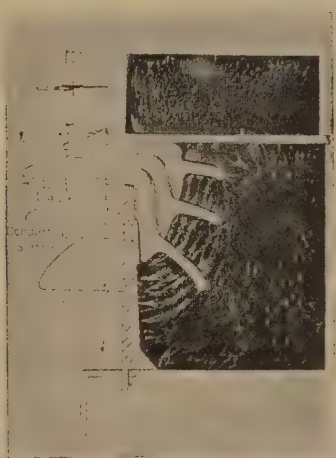


Fig. 86.

3. The capacity of each shell is approximately the same.

4. The air path between shells is sufficient to prevent corona formation at normal voltages and the rain sheds are so spaced that each section takes its share of the stress at flashover.

With an insulator properly designed there will be no points of overstress either wet or dry. In this case there will be no incipient arcs between adjacent sheds or across highly stressed sections and as a consequence a maximum flashover value will be obtained. The voltage distribution of each shell depends upon the capacity current and the leakage current. When dry the leakage current is small compared with the capacity current but when wet the reverse is true. With an insulator designed to have equal capacity per shell as well as equal leakage current, the voltage distribution will be approximately equal for each shell under all operating conditions.

The modern designs of pin type insulators, although rated the same by their various manufacturers, will vary considerably as to wet and dry flashover. It must be remembered that the nominal rating is an arbitrary figure assumed by the manufacturer as the line voltage under which his insulator will operate satisfactorily under the *most favorable* weather conditions. By this is meant climatic conditions where the insulator is exposed to no exceptional dust or dirt as would be found along a highway, or a railroad, or in the vicinity of industrial plants. This condition would also assume clear air away from the sea coast and where rains were frequent but not torrential and where lightning was not severe. As such conditions are hard to imagine it may be truthfully said that the "nominal" rating is an overrating. For instance manufacturers usually rate an insulator that they expect to be used on 33 kv. lines at 45,000 volts.

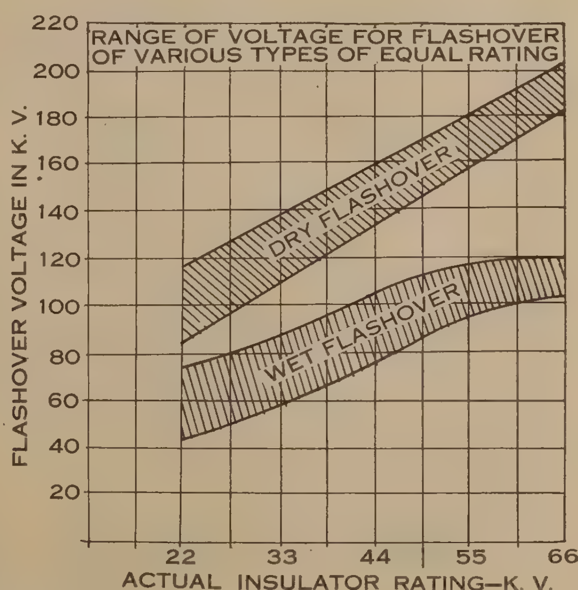


Fig. 87.

Figure 87 covers the wet and dry flashover range of nearly all insulator manufacturers in actual ratings. It will be noted that in the actual or recommended ratings there is a variation of from 20 to 25 per cent in the flashover. A part of this is due to the insulators themselves although a portion of the variation can be charged to the fact that flashovers at best are approximate within a range of 10 or 15 per cent. The wet flashover value is particularly hard to determine and accuracy cannot be obtained as easily as with the dry

flashover. It will be noted in Fig. 87 that for the wet flashover a greater per cent variation was obtained on the wet test than on the dry. For this reason there may be some justification in rating an insulator on its dry test for comparative values. However, for the acutal application of an insulator to a particular line the wet flashover is of the greater importance. The flattening of the wet flashover curve in Fig. 87 and the straight line of the dry flashover are worthy of consideration.

In Fig. 88 curves of wet and dry flashover, weight and actual rating indicate the average relation between these values. It will be noted that the actual rating of a pin type insulator is one-half the wet flashover and one-third the dry flashover, this ratio dropping as the rating increases. The increasing weight curve and the decreasing one-half-wet-flashover curve indicate very clearly the limitation in size of pin type insulator. Also when it is considered that the larger the insulator the lower the combined strength of arm, pin and insulator it can be readily understood that 66 kv. is the practical limit.

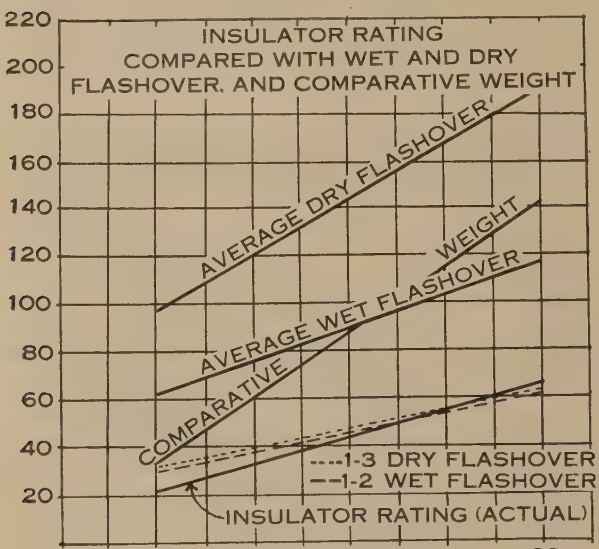


FIG. 88.

SUSPENSION INSULATORS

The first suspension insulator, the Buck-Hewlett type, designed in 1906, went in to service on lines in Michigan and Colorado about July, 1908. Almost immediately the cap-and-pin suspension was developed, the general appearance of the original being much the same as the standard insulator of today. Several years later a third type, the core-and-tine, appeared, this insulator consisting of thick porcelain in direct tension. Thus we have three types of suspension insulators: (1) the cap-and-pin, generally accepted as a standard having better electrical and mechanical characteristics and working the porcelain to the best advantage mechanically, (2) the Hewlett, or bomb-and-link, working the porcelain to some extent in direct compression, and (3) the J-D, or core-and-tine, which works the porcelain in tension.

The cap-and-pin was used extensively by 1910 but by 1913 failures were so widespread that the design was given considerable attention with the resulting improvement. The failures were due to mechanical strains set up by the differences in expansion between porcelain, cement and metal and also to a poor grade of porcelain, not only porous but generally defective due to manufacturing processes. These faults have all been eliminated by methods of assembly and by better porcelain until the present insulator certainly can be predicted to have a life of twenty-five or thirty years and in fact an unlimited life where over loading can be avoided. It has been found that some of the earlier insulators, even with all of the original troubles, failed only 20 per cent in twelve years of service where the loading was light. With this length of life on the original design it is not too much to expect the standard insulator of today to have a life of thirty years or more, if not overloaded mechanically or electrically.

The electrical characteristics of the suspension unit are:

1. Puncture value.
2. Flashover value.
3. Voltage distribution.

With the puncture value of an insulator 50 per cent over its flashover voltage, surges due to lightning or other causes may result in flashovers with no resulting

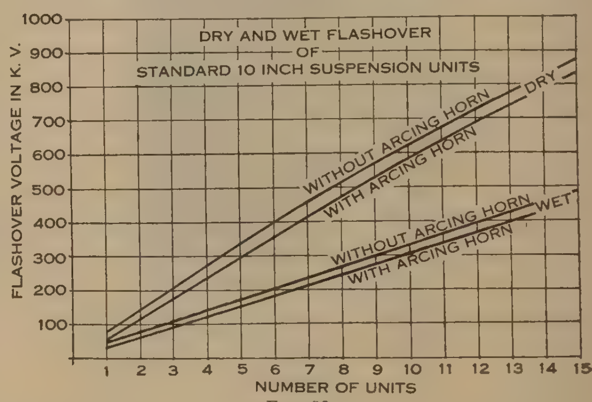


FIG. 89.

damage to the line, whereas, with a low puncture value, overvoltage would probably result in permanent line trouble. It is the practice to consider a puncture value of 150 per cent of the dry flashover as sufficient. As a matter of fact cap-and-pin insulators, with a dry flashover of approximately 80 kv., have a puncture value seldom less than 150 kv.

The wet and dry flashover values depend upon arcing and leakage distance and upon the insulator spacing or, in other words, upon the outline dimensions. Flashover of a string of standard insulators will depend almost directly on the length of the string. The spacing should therefore be as great as possible. But with too great

spacing the flashover arc will tend to cascade from one cap to the next resulting in greater damage to the insulator string. It has been established fairly definitely that an insulator spacing of 6 in. is not too great, with the result that spacings from 5½ in. to 5¾ in. are in general use. The curves in Fig. 89 indicate flashover values for standard cap-and-pin insulators.

The arcover voltage of a string of insulators is less than the sum of arcover voltages of the separate units. This is due to the voltage distribution across the various units, the line disc taking a much greater proportion of the total voltage than that next to the tower. The cause of this uneven voltage distribution is in turn due to the capacities of the hardware and fittings to line and to ground causing a decreasing capacity current through the insulator. With the series current flowing through the insulator affected by current from line to cap and from cap to ground, there will be a decreasing current for each unit away from the line and with a difference of current will follow a difference in voltage drop on each insulator.

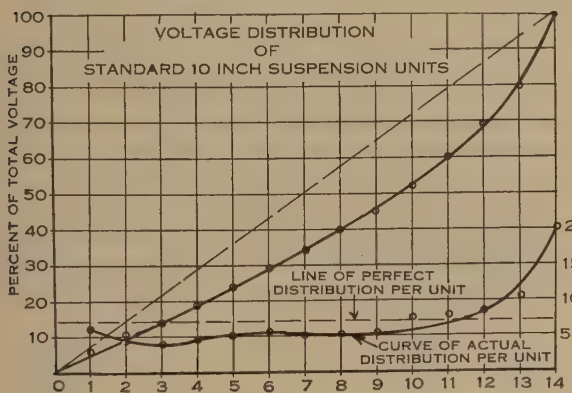


Fig. 90.

Voltage distribution on cap-and-pin insulators does not have much effect below 165,000 volts but lines at that voltage and above require some means for correcting the excess voltage on the line units. So far the 165 kv. lines have used a splash plate below the bottom disc in order to prevent incipient arcing due to the lower side only of this disc remaining dry during rain. This plate has had some effect on the voltage distribution also. On the 220 kv. lines it has been felt necessary to add actual corrective measures to straighten the voltage distribution curve. The two methods that have been adopted are: (1) distribution rings, and (2) graded insulators.

Distribution rings have the effect of increasing the capacity to ground of the line insulator at the same time reducing the capacity between intermediate insulator members and their adjacent members. This decreases the relative potential of the insulators nearest the line and increases that of the intermediate insulators, thus making the gradient curve more uniform. Grading the string consists of the use of larger insulators of higher capacity on the line end of the string.

In Fig. 90 a voltage distribution curve is shown for a suspension string of 14 standard 10 in. units of the cap-

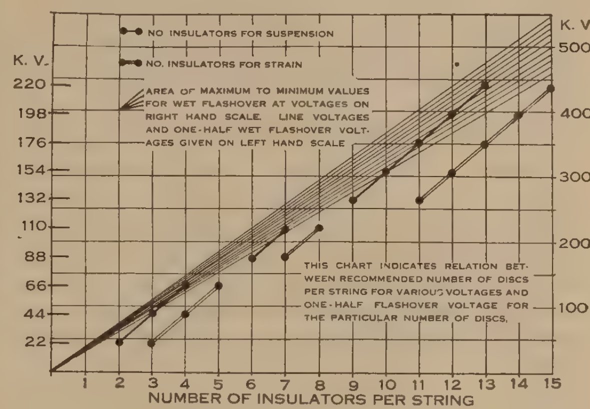


Fig. 91.

and-pin type. It will be noted that the voltage distribution over the line unit is less than 20 per cent. The distribution of the bomb-and-link and core-and-tine are considerably higher varying from 30 to 35 per cent.

The number of discs per string for various voltages depends upon the location and the importance of the line. Some of the earlier 100 kv. lines used but four discs while at least one 66 kv. line is now using eight. In general the best method of determining the correct number of units is to assume that the wet flashover of the string should be double the line voltage. If climatic conditions are severe or service requirements great a longer string should be used. The curve in Fig. 91 indicates approximately the correct number of units that should be used.

CHAPTER XVIII

SPEED OF ELECTRIC PROPAGATION—RESONANCE—PARALLELING TRANSMISSION CIRCUITS—HEATING OF BARE CONDUCTORS IN AIR

SPEED OF ELECTRIC PROPAGATION

Astronomers and investigators by various methods of determination have arrived at slightly different values for the speed of light. The Smithsonian Physical Tables give 186,347 miles per second as a close average estimate. In electrical engineering, the speed of light is usually stated as approximately 3×10^{10} centimeters per second. This is the equivalent of 186,451 miles per second. The speed of electrical propagation (assuming zero losses) is the same as that of light.

ELECTRIC WAVE LENGTH

Suppose a frequency of 60 cycles per second is impressed upon a circuit of infinite length. At the end of one sixtieth of a second the first impulse (neglecting retardation due to losses) will have traversed a distance of 186,347 ÷ 60 or 3,106 miles. A section of such a circuit 3,106 miles long would be designated as having a full wave length for a frequency of 60 cycles per second.

In Fig. 92, the dotted line or one cycle wave is shown as extending over a circuit 3,106 miles long. In this case, when the first part of the wave arrives at a point 3,106 miles distant, the end of the same wave is at the beginning of the circuit. For each half wave length the current is of equal value but flowing in opposite directions in the conductor. Such a circuit is designated as of full wave length. Since the velocity of the electric propagation is slightly less than that of light, being slightly retarded due to resistance and leakage losses, the actual wave length will be slightly less than 3,106 miles. Thus for a 300 mile, 60 cycle, three-phase circuit consisting of No. 000 copper conductors having 10 ft. flat spacing, the wave length is calculated to be 2,959 miles. The wave length of such a circuit is indicated by the heavy line on the accompanying sketch. In the case of this particular circuit the electric field has been retarded approximately five per cent, due to the losses of the circuit, as indicated by the displacement of the dotted and full line curves.

QUARTER WAVE RESONANCE

If the end of a long trough filled with water is struck by a hammer, the impact will cause a wave in the water to start in front of the point of impact and travel to the far end of the tank. When this wave reaches the far end of the tank it will be reflected, traveling back toward the point of origin, but on account of resistance encountered it will be of diminishing height or amplitude. If, at the instant it gets back to the point of origin, the end of the tank is again struck by the hammer, the resulting impulse will be that due to the second hammer blow plus that remaining from the first blow. The result will be that the second wave from the near end of the tank will be of greater amplitude than the first wave. If when the second wave arrives back at the near end, the end of the tank is struck again with the hammer the resulting third impulse will be of greater amplitude than the second impulse. If at the instant of the return of each succeeding impulse the end of the tank is struck, the result will be cumulative and each succeeding wave will be of greater magnitude than the one preceding until the point is reached where the losses due to resistance become sufficient to prevent a further increase in amplitude of the wave.

Under certain conditions a similar phenomenon may occur in electric circuits and this is known as "quarter wave resonance." If an electric impulse* is sent into a

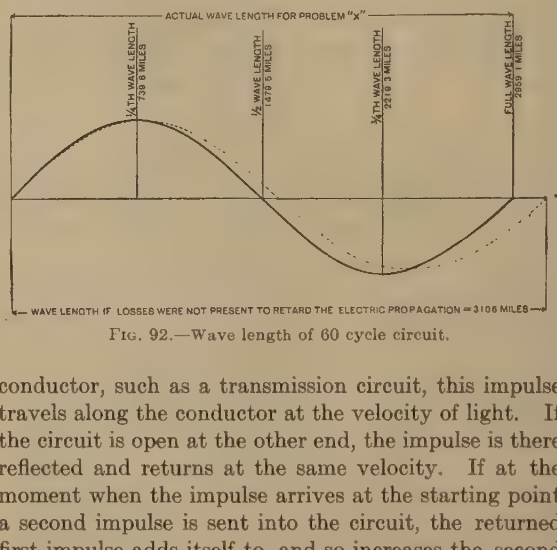


Fig. 92.—Wave length of 60 cycle circuit.

conductor, such as a transmission circuit, this impulse travels along the conductor at the velocity of light. If the circuit is open at the other end, the impulse is there reflected and returns at the same velocity. If at the moment when the impulse arrives at the starting point a second impulse is sent into the circuit, the returned first impulse adds itself to, and so increases the second impulse; the return of this second impulse adds itself to the third impulse, and so on; that is, if alternating impulses succeed each other at intervals equal to the time required by an impulse to travel over the circuit and back, the effects of successive impulses add themselves, and large currents and high e.m.f.'s may be produced by small impulses. This condition is known as quarter wave electric resonance. To produce this

* For a complete study of this subject see "Transient Electric Phenomena and Oscillations" by C. P. Steinmetz, from which the above description of quarter wave resonance has largely been taken.

condition, it is necessary that the alternating impulses occur at time intervals equal to the time required for the impulses to travel the length of the line and back. For example, the time of one half wave or cycle of impressed e.m.f. is the time required by light to travel twice the length of the line, or the time of one complete cycle is the time light requires to travel four times the length of the line. Stated another way, the number of cycles or frequency of the impressed alternating e.m.f.'s in resonance condition, is the velocity of light divided by four times the length of the line; or to have free oscillation or resonance condition, the length of the line is one quarter wave length of light. The cycles at which this condition is reached (if there were no losses present) would be determined as follows:

$$\textit{Frequency} = \frac{46{,}587}{\textit{Length in miles}} \quad \text{(23)}$$

or

$$\textit{Length in miles} = \frac{46{,}587}{\textit{Frequency}} \quad \text{(24)}$$

RESONANCE LENGTHS OF CIRCUITS

Commercial frequencies are so low that to reach a quarter wave resonance condition with them the circuit would have to be of great length. The following values, for the sake of simplicity, are based upon the assumption that there are no losses in the circuit.

Fundamental Frequency	Resonance Length	Wave Length
15 cycles	3,106 miles	12,424 miles
25 cycles	1,863 miles	7,452 miles
40 cycles	1,165 miles	4,660 miles
60 cycles	776 miles	3,106 miles

The above lengths are based upon the impressed or fundamental frequencies. If these impressed frequencies contain appreciable higher harmonics, some of the latter may approach resonance frequency and, if of sufficient magnitude, may cause trouble. Thus the length of circuit corresponding to resonance conditions of various harmonics of the fundamental is given below.

Cycles	Harmonics		
	3rd.	5th.	7th.
15	1,035 miles	631 miles	444 miles
25	621 miles	372 miles	266 miles
40	388 miles	233 miles	166 miles
60	258 miles	155 miles	111 miles

Thus an impressed frequency of 60 cycles will not produce quarter wave electric resonance unless the circuit be approximately 776 miles long. If a third harmonic, however, is present in the impressed wave, this harmonic will develop quarter wave resonance in a circuit approximately 258 miles long, a 5th harmonic in a circuit approximately 155 miles long, and a 7th harmonic in a circuit approximately 111 miles long.

The above values are based upon no losses being encountered in transmission. Obviously this is an incorrect assumption, as electric propagation is always accompanied by more or less loss, depending upon the fundamental constants (resistance and leakage) of the circuit. The effect of such losses is to retard the velocity of the electric propagation, usually by an amount of five to ten per cent below that of light. The above values of circuit lengths representing a condition for resonance may therefore be as much as ten per cent above the actual lengths.

An investigation of the effects of higher harmonics of the impressed wave is of importance in connection with very long distance transmission systems.

PARALLELING TRANSMISSION CIRCUITS

PHASING OUT

Transmission lines are frequently constructed with duplicate circuits which are normally operated in parallel. In other cases two circuits may lead from the generating station in divergent directions and at some distant point come together and be connected in parallel.

If the two circuits are fed from different generators, or sources of supply, the only condition necessary for paralleling the circuits is that the phase rotation of the two circuits be the same and that the regulation in speed of the prime movers of the generators feeding the two systems can be adjusted so as to bring the phases of the two circuits together for paralleling.

If, however, the two circuits which are to be connected in parallel are fed from the same source of supply, the case may become involved. There will be no trouble in obtaining the correct phase rotation, for should the circuits not rotate alike, it is only necessary to transpose any two of the connections of either of the circuits (assuming that the circuits are three-phase). The other condition to be met is that the phases of both circuits to be paralleled are the same, i.e., the voltages in the phases to be paralleled must pass through their zero and maximum values at the same instant.

If neither circuit has transformers between the points where they are to be connected in parallel, their phases will coincide and there will be no trouble about connecting them in parallel. If one circuit has no transformers and the other has transformers, the phase relations of the two circuits will depend upon the kind of transformer connections employed. Let it be assumed that the raising transformers are connected delta to star and the lowering transformers are connected delta to delta. With these connections the phases of the two circuits will be 30 electrical degrees apart and it will be impossible to parallel the circuits. In other words one delta-star or star-delta transformer connection produces a phase displacement of 30 degrees. It will be obvious that a second delta-star or star-delta connection will restore the original phase relation. A delta-delta connection or a star-star connection does not affect the phase relations. If both circuits have an even number of star and an even number of delta wind-

ings, the equivalent resultant will be the same as if all the connections were either delta-delta or star-star; hence, there will be no resultant change in phase relations and the two circuits can be paralleled with each other or with a circuit having no transformations. If, however, both circuits have an odd number of delta and an odd number of star windings, any attempt to resolve them into the equivalent number of delta-delta and star-star connections will leave one star and one delta; the effect is the same as if there was one star-delta connection in the circuits. This will twist the phase relations of the terminals 30 degrees out of phase from the generators. Since both circuits will have an equivalent phase displacement, they can be paralleled with one another, but since both are 30 degrees out of phase with the generators, they cannot be paralleled with a line having no transformations; nor with a line having an even number of star and delta connections.

When the phase angles of the two transmission circuits (receiving their power from a common source) are known to be such as to permit of parallel operation, it is then necessary to phase them out before connecting the circuits together. The phase rotation can be checked most readily by means of a polyphase motor connected first to one circuit and then to the other, being careful to connect the leads in the same order in each case. If the motor runs in the same direction from both circuits, the phase rotation of the circuits will be the same. The phase angle can be readily tested by means of a single-phase synchroscope.* In case a polyphase motor and synchroscope are not available, the phasing out of the circuits may be

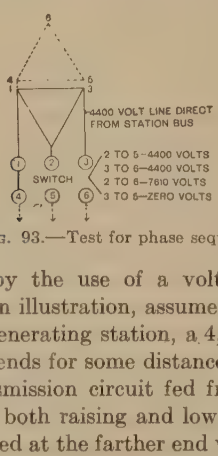


Fig. 93.—Test for phase sequence.

accomplished by the use of a voltmeter and transformer.† As an illustration, assume that from a 4,400 volt bus in a generating station, a 4,400 volt transmission circuit extends for some distance from the station. A second transmission circuit fed from the same bus but containing both raising and lowering transformers is to be paralleled at the farther end with the 4,400 volt circuit which contains no transformers. The phase angles of the lines are assumed to be such as to permit paralleling the two circuits, with proper connections.

One of the transmission circuits is connected to one side of the paralleling switch as in Fig. 93 and the other circuit to the other side of the same switch. The three terminals on one side of the switch may be tagged 1-2-3. Likewise the three terminals on the other side of the switch may be tagged 4-5-6. Connect any two terminals together (1 and 4 in this case) by a jumper. Take voltage readings across the corresponding terminals 2 to 5, 3 to 6, and 3 to 5, 2 to 6. From these voltage readings it is a simple matter to indicate by a vector diagram the relative phase relations at the switch contacts of the two circuits to be paralleled. In the case illustrated, the readings indicate that the relative voltage relations on the two sides of the paralleling switches are as indicated by the full line delta 1-2-3, and the broken line delta 4-5-6. It will be seen that phase 1-3 will parallel with phase 4-5, that phase 1-2 will parallel with phase 6-5 and phase 2-3 will parallel with phase 4-6. In order to bring about this phase relation it will be necessary to change the transformer connections on the low-tension side of the lowering transformers, inside of the delta. That is, the 6 end of the transformer windings 5-6 will be connected to the 4 end of transformer 4-5. The 4 end of transformer 4-6 will be connected to the 5 end of transformer 5-6, and the 6 end of transformer 4-6 will be connected to the 5 end of transformer 4-5. These changes will shift the position of the delta 4-5-6 so that it will coincide with delta 1-2-3. A further test of voltage between switch terminals 2 to 5 and 3 to 6 should indicate zero voltage across the switch terminals to be connected together, in which case the paralleling switches may be closed. In order to measure the voltage across the paralleling switch contacts it will usually be necessary to employ a potential transformer. This transformer and voltmeter should be capable of withstanding 2.00 times the voltage of the circuit, for, with the connections given in Fig. 93, one reading gave 7,610 volts, whereas the voltage of the circuit was only 4,400 volts.

In case there is a ground on both systems, the placing of a jumper across two of the switch contacts would result in a short-circuit. This jumper should not be placed across the switch until it has been shown by connecting a transformer across these two contacts that no potential exists between them.

DIVISION OF LOADS

When transformer banks are to be operated in parallel, careful consideration is given to providing proper constants in the transformers, so that each bank will take its proper share of the total load. When transmission lines are to be paralleled, however, the question of division of the load among the circuits in parallel is too often not investigated as thoroughly as its importance would dictate. Simply adding more copper or aluminum or stepping up the voltage of the new line, which is to be paralleled with the existing line, will not necessarily provide the additional load carrying capacity that the additional size of conductors or higher

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* These tests are described in an article on "Phasing Out High Tension Lines" by E. C. Stone in the Electric Journal for Nov., 1917, p. 448.

† This method is described in an article on "Determination of Polarity of Transformers for Parallel Operation" by W. M. McConahey, in the Electric Journal for July, 1912, p. 613. See also an article on "Polarity of Transformers" by W. M. Dann in the Electric Journal for July, 1916, p. 350.

voltage may seem to indicate. The circuit constants of the new line may be such that when paralleled with an existing line, it will not take anywhere near its share of the total load. For this reason, it may not at all justify its cost, provided parallel operation is a requisite.

When two circuits are to operate in parallel, their constants must be such, that when each is carrying its share of the total load, their voltages, in both amount and direction will be the same. Obviously after they are connected together this voltage relation must exist. If either the voltages or their phases do not correspond, a current will circulate between the two circuits which will so modify the line drops and power factors in the two circuits, as to bring about the necessary common voltage relation.

The cases reviewed above are comparatively simple. The extensive interconnection of different high voltage systems, sometimes through 3 winding transformers, introduces many complications. Sometimes large blocks of power will come from a generating station located at one point of the network, sometimes from a generating station at a different point and sometimes part of the power will come from scattered generating stations. Then again sub-stations distributed along the lines cause a variation in power and phase displacement from point to point. To calculate accurately the distribution of current under some of these complicated system lay-outs would be most difficult. It is usually sufficient to calculate approximately what it would be under some emergency condition and to furnish proper taps on transformers and, sometimes, induction regulators so as to bring the voltages reasonably close together under these conditions.

The general method of calculation for parallel circuits is indicated by the following numerical solutions for certain typical cases. It should be noted that in order to obtain a more exact check on the accuracy of the numerical results than would be obtained by the use of three figure tables of constants, the constants have been determined and the original calculations carried out to five figure accuracy. In the solutions which follow, the exact results have been abbreviated to three or four figures so that the values shown will not always agree precisely with those derived from the actual figures appearing in the various solutions.

Case 1

Dissimilar Circuits in Parallel (No Transformers)

In the accompanying diagrams of Fig. 94 illustrating the division of current between two circuits in parallel, without transformers, we have neglected the effect of line admittance. This is not included here, because its effect on the division of the load is, unless the line is electrically long, too small to justify the complication introduced in taking it into account.

Based on impedance only, and referring to the table of general circuit constants on page 144, the constants of the individual circuits are as in Network No. 1. The overall constants for the two lines together, as in Network No. 17 are

$$A = \frac{1 \times Z_2 + Z_1 \times 1}{Z_1 + Z_2} = 1$$

$$B = \frac{Z_1 Z_2}{Z_1 + Z_2}$$

$$C = 0$$

$$D = \frac{Z_1 \times 1 + 1 \times Z_2}{Z_1 + Z_2} = 1$$

Thus the constants are those of an impedance $\frac{Z_1 Z_2}{Z_1 + Z_2}$ which is simply the ordinary expression for the combined impedance of two impedances in parallel.

Assume that a 33,000 volt, 3 phase, 60 cycle transmission circuit, 50 miles long, consisting of three No. 0000 copper conductors with 3 ft. spacing, has become loaded and a second circuit of three 500,000 circ. mil. copper conductors with 3 ft. spacing is to be added in parallel with it. We will assume a load of 10,000 kv.a., (8,000 kw.), 3 phase, at 80 per cent P.F. lagging is to be delivered at 33,000 volts over the two circuits in parallel. The impedances are as in the lower diagram of Fig. 94. Then

$$E_{rn} = \frac{33{,}000}{\sqrt{3}} = 19{,}053 \text{ volts.}$$

$$I = \frac{10{,}000}{3 \times 19.053} = 175 \text{ amp.}$$

$$= 175(.8 - j.6) = 140 - j105 \text{ amp. to } E_{rn}$$

$$B = \frac{(13.88 + j31.84)(5.98 + j28.8)}{19.86 + j60.64}$$

$$= 4.72 + j15.3$$

From equation (49) on page 148

$$I_1 = 0 + (140 - j105)\frac{4.72 + j15.3}{13.88 + j31.84}$$

$$= 69.5 - j40.9$$

$$= 80.65 \text{ amp.}$$

Similarly,

$$I_2 = 0 + (140 - j105)\frac{4.72 + j15.3}{5.98 + j28.8}$$

$$= 70.5 - j64.1$$

$$= 95.24 \text{ amp.}$$

As a check

$$\begin{aligned} I_1 &= 69.5 - j40.9 \\ I_2 &= \underline{70.5 - j64.1} \\ I &= 140.0 - j105.0 \\ &= 175\overline{\diagdown 36° 52'} \text{ amp. to } E_{rn}. \end{aligned}$$

The sending end voltage, E_{sn}, based on circuit Z_1 and equation (5) on page 141 is

$$E_{sn} = 19{,}053 \times 1 + (69.5 - j40.9)(13.88 + j31.84)$$

$$= 21{,}320 + j1{,}646$$

$$= 21{,}383\underline{/4° 25'} \text{ volts.}$$

The same result is obtained by circuit Z_2 and current I_2.

Using the overall constants for the two lines together we get, from equation (5)

$$E_{sn} = 19{,}053 \times 1 + (140 - j105)(4.72 + j15.3)$$

$$= 21{,}320 + j1{,}646$$

which is identical with the above.

In alternating current circuits power is not, as in direct current circuits, the product of voltage and current or $E \times I$. The explanation of this is rather involved, but is treated quite fully by Charles Fortescue in the Appendix to his paper on The Measurement of Power in Polyphase Circuits.* Power in alternating current circuits is, instead, the product of voltage and the conjugate of the current, the conjugate of a complex quantity being the quantity with the sign of its j term changed.

Thus with alternating current, and denoting vectors by $\dot{E}$, $\dot{I}$, etc. and conjugates by $\underset{.}{E}$, $\underset{.}{I}$, etc.

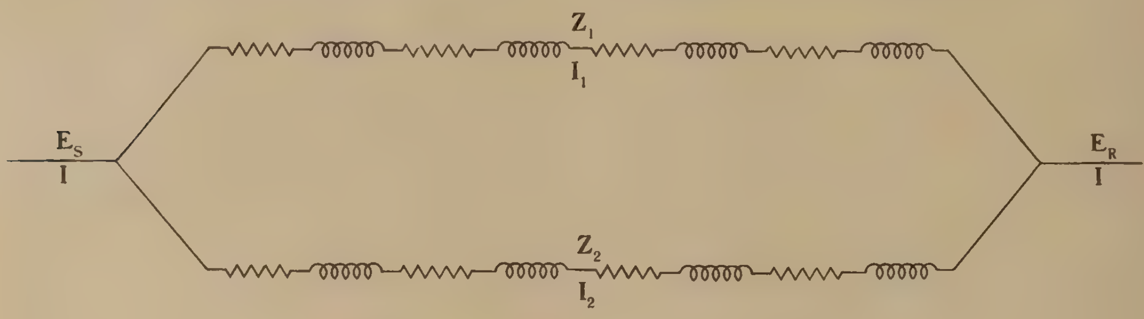
$$\text{Power} = P + jQ = \dot{E}\underset{.}{I}.$$

$$\begin{aligned} P_{rn1} + jQ_{rn1} &= 19.053(69.5 + j40.9) \\ &= 1{,}324.4 + j779.1 \\ P_{rn2} + jQ_{rn2} &= 19.053(70.5 + j64.1) \\ &= 1{,}342.3 + j1{,}220.9 \\ P_{rn} + jQ_{rn} &= 2{,}666.7 + j2{,}000 \text{ kv.a. per phase.} \end{aligned}$$

Total power at the receiving end

$$\begin{aligned} P_r + jQ_r &= 3(2{,}666.7 + j2{,}000) \\ &= 8{,}000 + j6{,}000 \\ &= 10{,}000 \text{ kv.a.} \end{aligned}$$

which checks with the original load of 10,000 kv.a. at .8 power factor.



CASE 1

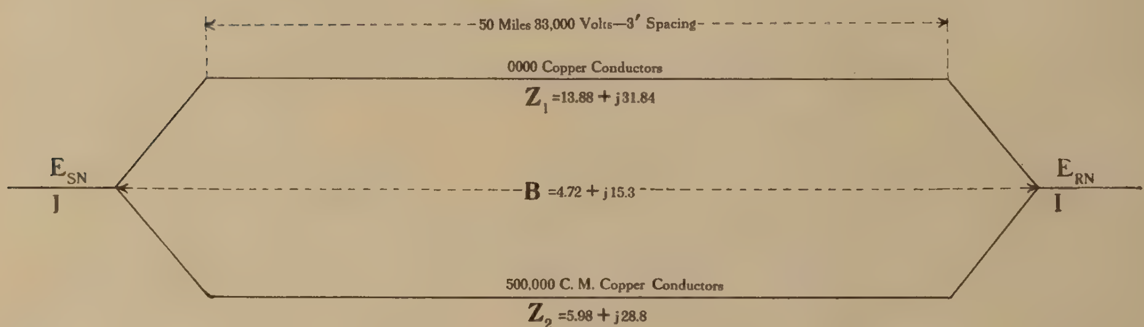


Fig. 94.

in which P is the true power and Q the reactive, or wattless power.

Thus, assuming a voltage E and a lagging current $I_1 - jI_2$

$$\begin{aligned} P + jQ &= E(I_1 + jI_2) \\ &= EI_1 + jEI_2 \end{aligned}$$

in which the sign of the reactive power term is positive for a lagging power factor. The same reversal of sign will occur with leading power factors and power and current in the same calculation or diagram must therefore be represented by opposite signs for the reactive term.

Then, in the above case, we have at the receiving end, for the power in the individual circuits, using kv. as the unit of voltage—

At the sending end

$$\begin{aligned} P_{sn1} + jQ_{sn1} &= (21.32 + j1.646)(69.5 + j40.9) \\ &= 1{,}414.7 + j986.2 \\ P_{sn2} + jQ_{sn2} &= (21.32 + j1.646)(70.5 + j64.1) \\ &= 1{,}396.6 + j1{,}482.2 \\ P_{sn} + jQ_{sn} &= 2{,}811.3 + j2{,}468.4 \text{ kv.a. per phase.} \end{aligned}$$

Total power at sending end

$$\begin{aligned} P_s + jQ_s &= 3(2{,}811.3 + j2{,}468.4) \\ &= 8{,}434. + j7{,}405 \\ &= 11{,}224 \text{ kv.a.} \end{aligned}$$

$$\begin{aligned} \text{Power loss} &= 8{,}434 - 8{,}000 \\ &= 434 \text{ kw.} \\ &= 5.43 \text{ per cent of } P_r \\ \text{Voltage drop} &= 21{,}383 - 19{,}053 \\ &= 2{,}330 \text{ volts} \\ &= 12.2 \text{ per cent of } E_{rn} \end{aligned}$$

* *Transactions*, A. I. E. E., Feb., 1923, Vol. XLII, p. 364.

The power loss as above may be checked by the I^2R losses.

Thus:

$$\text{Loss in circuit } Z_1 = 3 \times 80.65^2 \times 13.88$$
$$= 271 \text{ kw.}$$
$$\text{Loss in circuit } Z_2 = 3 \times 95.24^2 \times 5.98$$
$$= 163 \text{ kw.}$$
$$\text{Total power loss} = 434 \text{ kw. as above.}$$

It is interesting to compare the above results for the 50 mile, 60 cycle circuits, based on the impedance method, with the rigorous values obtained by using the distributed constants of the two circuits and including the line admittance. A comparison of the more important items is given below.

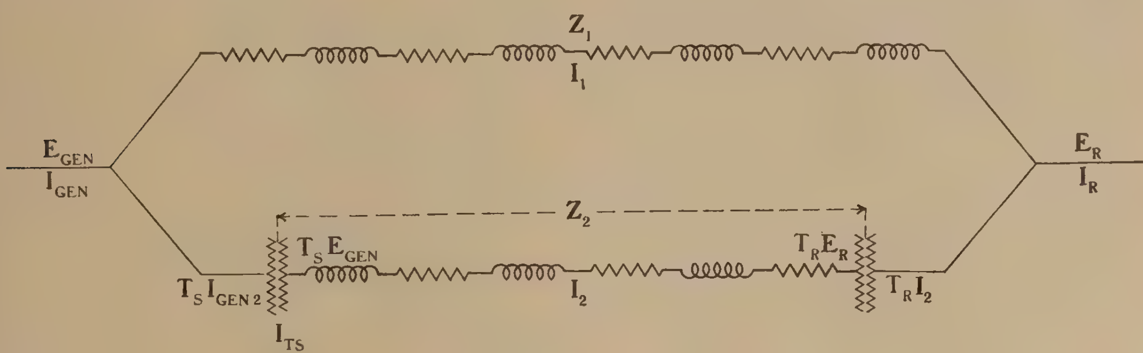
	By Impedance Method	By Distributed Constants
I_{r1}	80.65	80.43
I_{r2}	95.24	95.43
I_{s1}	80.65	76.89
I_{s2}	95.24	90.28
I_s	175	166
E_{sn}	21,383	21,278
P_{sn}	2,811	2,805
Power loss per phase	144	138
Voltage drop	2,330	2,225

There is a slight change in the distribution of current between the two circuits. The greatest difference is found in the sending end current which is nearly 5.5 per cent greater by the impedance method than by the rigorous method, while power loss and voltage drop are each about 4.5 per cent greater.

It will be seen that there is only a very small difference between the amount of true power transmitted over the two circuits, and from the point of view of sharing the load the 500,000 circ. mil conductors could be replaced by smaller conductors with very little effect on load distribution or regulation.

If, in place of employing 500,000 circ. mil. conductors in the second circuit, we employ No. 0000 copper, the same as in the first circuit the impedance of the two circuits will be equal. In this case half the power will flow over each of the circuits and we obtain the following for each circuit:

$$I = 70 - j52.5$$
$$= 87.5 \text{ amp. absolute}$$
$$\text{Power loss} = (87.5)^2 \times 13.88 = 106.3 \text{ kw.}$$
$$= 319 \text{ kw. total}$$
$$E_{sn} = 19{,}053 + (70 - j52.5)(13.88 + j31.84)$$
$$= 21{,}696 + j1{,}500$$
$$= 21{,}748\underline{/3^\circ\,57'} \text{ volts}$$
$$\text{Voltage drop} = 21{,}748 - 19{,}053 = 2{,}695 \text{ volts}$$
$$= 14.1 \text{ per cent of } E_{rn}$$



CASE 2

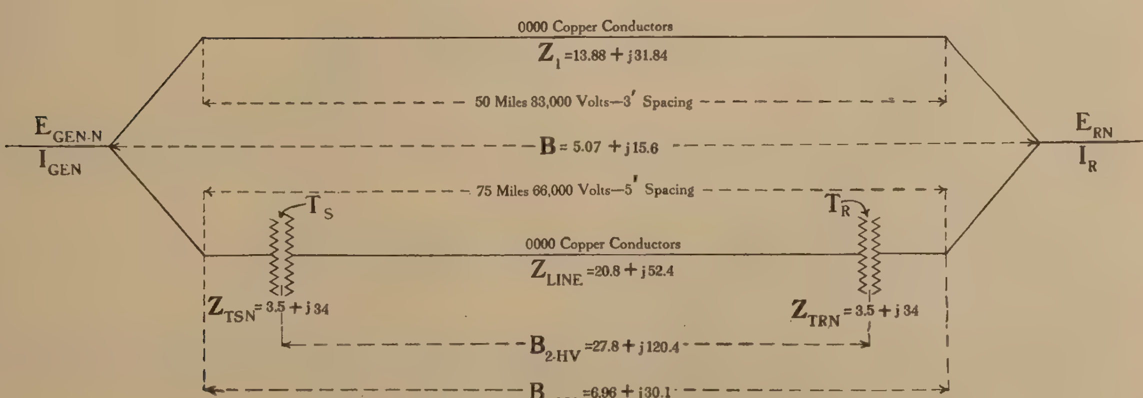


FIG. 95.

The employment of the larger and more expensive 500,000 circ. mil. copper conductors then gives a saving in energy loss for both circuits of $(2 \times 319) - 434$ or 204 kw. and in voltage drop of $14.1 - 12.2 = 1.9$ per cent.

Case 2

Transformers in One Circuit (Impedance Solution)

Figure 95 illustrates two circuits in parallel, one of which has transformers and the other has not. This case assumes the delivering of 15,000 kv.a. (12,000 kw.) at 80 per cent lagging P.F. at 33,000 volts, 3 phase, 60 cycles, over a circuit of three No. 0000 copper conductors with 3 ft. spacing, 50 miles long, in parallel with a 66,000 volt, 3 phase, 60 cycle circuit of three No. 0000 copper conductors with 5 ft. spacing, 75 miles long, having transformers at both ends.

From the figure the constants of circuit Z_1 are the same as in the previous example. Circuit Z_2 consists of three impedances in series and referring to the lower diagram, and the equations for Networks Nos. 1 and 16 on page 144 we have for the general circuit constants of circuit Z_2, referred to high voltage.

$$A_{2-hv} = 1(1 \times 1 + 0 \times Z_{line}) + Z_{tn}(1 \times 0 + 0 \times 1) = 1$$

$$B_{2-hv} = 1(Z_{tn} \times 1 + 1 \times Z_{line}) + Z_{tn}(Z_{tn} \times 0 + 1 \times 1) = Z_{tn} + Z_{line} + Z_{tn}$$

$$C_{2-hv} = 0(1 \times 1 + 0 \times Z_{line}) + 1(1 \times 0 + 0 \times 1) = 0$$

$$D_{2-hv} = 0(Z_{tn} \times 1 + 1 \times Z_{line}) + 1(Z_{tn} \times 0 + 1 \times 1) = 1$$

The constants therefore, are simply those of an impedance Z_2 which is the sum of the individual impedances in the circuit, or

$$B_{2-hv} = 27.8 + j120.4$$

Before the constants of the individual circuits can be combined to form the overall constants of the two circuits together, those of circuit Z_2 must be expressed in terms of low voltage. This is done by means of the equations of Network No. 9, page 144, from which it will be noticed that the constants referred to low voltage are simply those referred to high voltage (Network No. 8), multiplied by simple functions of the transformer ratios T_r and T_s. In the present case it is assumed that the ratios are the same at both ends and

$$T = \frac{66,000}{33,000} = 2.$$

Then from the figure and Network No. 9, page 144

$$A_{2-lv} = 2/2 \times 1 = 1$$

$$B_{2-lv} = \frac{1}{2 \times 2}(27.8 + j120.4) = 6.96 + j30.1$$

$$C_{2-lv} = 2 \times 2 \times 0 = 0$$

$$D_{2-lv} = 2/2 \times 1 = 1$$

Also for the combined circuits in parallel and as in the previous case, $A = 1$, $C = 0$, $D = 1$ and

$$B = \frac{(13.88 + j31.84)(6.96 + j30.1)}{20.84 + j61.94}$$
$$= 5.07 + j15.6$$

As before, $E_{rn} = 19,053$ volts.

An exciting current I_{tr} is also assumed in the receiving end transformer of $0.55 - j4.72$ amp., referred to high voltage, and twice this amount, or $1.10 - j9.44$ amp., referred to low voltage. In the solution which will be given the exciting admittance of the raising and lowering transformers will not be considered in the determination of the A, B, C and D constants, but the effect of the transformers will be taken into account by adding the transformer exciting kv.a. to the load. Thus I_r and $P_r + jQ_r$ include the exciting current and exciting kv.a., respectively, of the receiving end transformer. Similarly I_{gen} and $P_{gen} + jQ_{gen}$ include the corresponding quantities of the sending end transformer.

$$I_l = \frac{15,000}{3 \times 19.053} = 262.4 \text{ amp.}$$
$$= 262.4(.8 - j6) = 210.0 - j157.5 \text{ amp. to } E_{rn}$$
$$I_{tr} = 1.1 - j9.4$$
$$I_r = 211.1 - j166.9$$
$$= 269.1\overline{\diagdown 38° \ 20'} \text{ amp. to } E_{rn}$$

As in Case 1

$$I_1 = (211.1 - j166.9)\frac{5.07 + j15.6}{13.88 + j31.84}$$
$$= 107.0 - j68.8$$
$$= 127.2 \text{ amp.}$$

Similarly

$$T_rI_2 = (211.1 - j166.9)\frac{5.07 + j15.6}{6.96 + j30.1}$$
$$= 104.1 - j98.1$$
$$= 143.0 \text{ amp.}$$

As a check

$$I_1 = 107.0 - j68.8$$
$$T_rI_2 = 104.1 - j98.1$$
$$I_r = 211.1 - j166.9$$

$$E_{gen-n} = 19,053 + (107.0 - j68.8)(13.88 + j31.84)$$

or

$$= 19,053 + (104.1 - j98.1)(6.96 + j30.1)$$

or

$$19,053 + (211.1 - j166.7)(5.07 + j15.6)$$
$$= 22,729 + j2,451$$
$$= 22,861\underline{/6° \ 09'} \text{ volts.}$$

The line current is the same at both ends of the circuit. Assuming the exciting current to be the same at both ends and noting that the angle between E_{gen-n} and E_{rn} is 6° 09′ we have

$$I_{ts} = (1.1 - j9.4)(\cos + j \sin) \ 6° \ 09'$$
$$= (1.1 - j9.4)(.994 + j.107)$$
$$= 2.1 - j9.3$$
$$T_rI_2 = 104.1 - j98.1$$
$$T_sI_{gen-2} = 106.2 - j107.4 = 151.0 \text{ amp.}$$
$$I_1 = 107.0 - j68.8$$
$$I_{gen} = 213.2 - j176.2$$
$$= 276.5\overline{\diagdown 39° \ 34'} \text{ amp. to } E_{rn}$$
$$P_{rn1} + jQ_{rn1} = 19.053(107.0 + j68.8)$$
$$= 2,038 + j1311$$
$$P_{rn2} + jQ_{rn2} = 19.053 \ (104.1 + j98.1)$$
$$= 1,983 + j1,869$$
$$P_{rn} + jQ_{rn} = 4,021 + j3,180 \text{ kv.a. per phase.}$$

Total power at receiving end

$$P_r + jQ_r = 3(4{,}021 + j3{,}180)$$
$$= 12{,}063 + j9{,}540 \text{ kv.a.}$$

which agrees with the original load of 15,000 kv.a. at .8 power factor plus the exciting kv.a. of the transformer. Thus

$$\text{Load kv.a.} = 15{,}000(.8 + j.6) = 12{,}000 + j9{,}000$$
$$\text{Transformer losses} = 19.053(1.1 + j9.4) \times 3 = 63 + \quad j540$$
$$= 12{,}063 + j9{,}540$$

At the sending end

$$P_{sn1} + jQ_{sn1} = (22.729 + j2.451)(107.0 + j68.8)$$
$$= 2{,}263 + j1{,}827$$
$$P_{gen-n2} + jQ_{gen-n2} = (22.729 + j2.451)(106.2 + j107.4)$$
$$= 2{,}150 + j2{,}700$$
$$P_{gen-n} + jQ_{gen-n} = 4{,}413 + j4{,}527 \text{ kv.a. per phase.}$$

Total power at sending end

$$P_{gen} + jQ_{gen} = 3(4{,}413 + j4{,}527)$$
$$= 13{,}239 + 13{,}581$$
$$= 18{,}965 \text{ kv.a.}$$
$$\text{Power loss} = 13{,}239 - 12{,}063$$
$$= 1{,}176 \text{ kw.}$$
$$= 9.75 \text{ per cent of } P_r$$

$$\text{Voltage drop} = 22{,}861 - 19{,}053$$
$$= 3{,}808$$
$$= 20 \text{ per cent of } E_{rn}$$

The difference in the true power at the sending and receiving ends can be checked as follows:

$$I^2R \text{ loss in circuit } Z_1 = 127.2^2 \times 13.88 = 225$$
$$I^2R \text{ loss in circuit } Z_2 = \left(\frac{143.0}{2}\right)^2 \times 27.8 = 142$$

Iron losses in sending end transformer = real part of $\dot{E}_s I_{ts}$

$$= 22.729 \times 2.1 - 2.451 \times 9.4 = 25$$
$$392$$

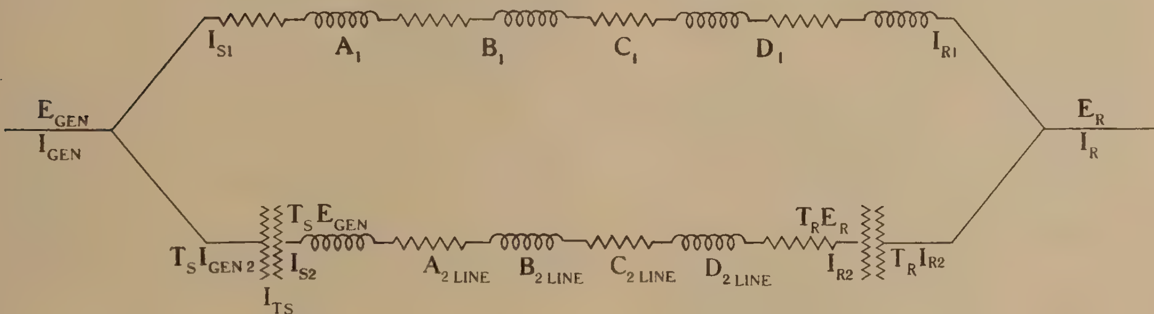
$$\text{Total loss} = 3 \times 392 = 1{,}176 \text{ kw. as above.}$$

A comparison of the above results by the impedance method with those by the rigorous solution, using line admittance and distributed line constants, will be found in the complete solution of the same problem which follows.

Case 3

Transformers in One Circuit (Complete Solution)

By complete solution is meant including not only the effect of exciting current of the transformer, but also the line admittance and distribution effect of the line constants in the calculations. The complication which



CASE 3

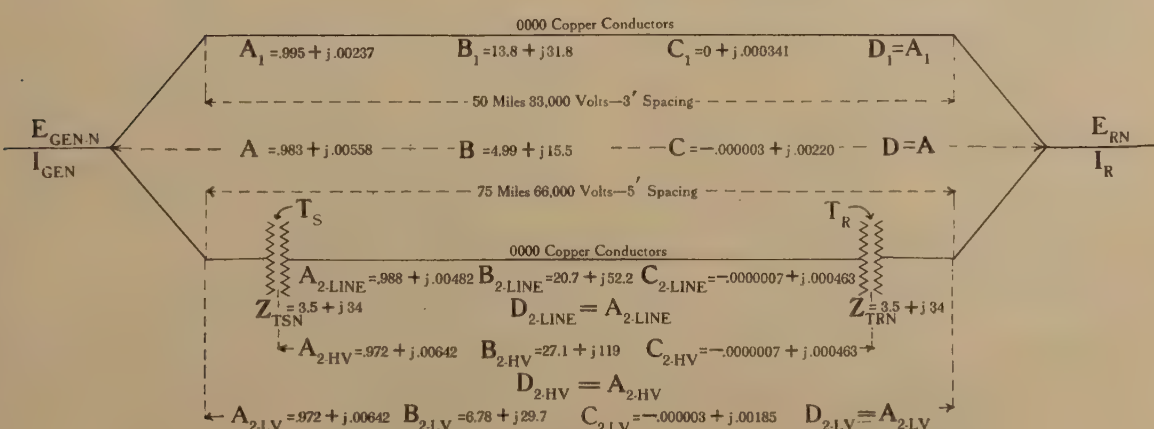


FIG. 96.

this introduces is hardly warranted in a line of this length by the slight improvement in accuracy of the results. There may be an occasional case where such high accuracy is required, but at any rate the procedure should be of academic interest. The line and load conditions are the same as in Case 2.

From Fig. 96 and tables of auxiliary constants we have

$$A_1 = .995 + j.00237$$
$$B_1 = 13.8 + j31.8$$
$$C_1 = 0 + j.000341$$
$$D_1 = A_1$$
$$A_{2-line} = .988 + j.00482$$
$$B_{2-line} = 20.7 + j52.2$$
$$C_{2-line} = -.0000007 + j.000463$$
$$D_{2-line} = A_{2-line}$$

From Network No. 8 the general circuit constants of the 66,000 volt circuit, referred to high voltage, are calculated as follows:

$$A_{2-hv} = (.988 + j.00482) + (-.0000007 + j.000463)(3.5 + j34)$$
$$= .972 + j.00642$$

Since the line is symmetrical and $Z_{tr} = Z_{ts}$

$$B_{2-hv} = (20.7 + j52.2) + (.988 + j.0048)(3.5 + j34) \times 2 + (-.0000007 + j.000463)(3.5 + j34)^2$$
$$= 27.1 + j119$$
$$C_{2-hv} = C_{2-line}$$
$$D_{2-hv} = A_{2-hv}$$

Since the transformer ratios are the same and equal to 2, the constants referred to low voltage are, from Network No. 9

$$A_{2-lv} = \tfrac{2}{2}(.972 + j.00642)$$
$$= .972 + j.00642$$
$$B_{2-lv} = \frac{1}{2 \times 2}(27.1 + j119)$$
$$= 6.78 + j29.7$$
$$C_{2-lv} = 2 \times 2(-.0000007 + j.000463)$$
$$= -.000003 + j.00185$$
$$D_{2-lv} = A_{2-lv}$$

From Network No. 17 the overall general circuit constants for the two circuits in parallel are as follows:

$$A = \frac{(.995 + j.00237)(6.78 + 29.7) + (13.8 + j31.8)(.972 + j.00642)}{(13.8 + j31.8) + (6.78 + j29.7)}$$
$$= .983 + j.00558$$
$$B = \frac{(13.8 + j31.8)(6.78 + j29.7)}{(13.8 + j31.8) + (6.78 + j29.7)}$$
$$= 4.99 + j15.5$$
$$C = (0 + j.000341) + (-.000003 + j.00185) + \frac{[(.995 + j.00237) - (.972 + j.00642)][(.972 + j.00642) - (.995 + j.00237)]}{(13.8 + j31.8) + (6.78 + j29.7)}$$
$$= -.000003 + j.00220$$
$$D = A$$

As in Case 2

$$E_{rn} = 19{,}053$$
$$I_r = 211.1 - j166.9$$
$$= 269.1 \diagdown 38° \; 20' \text{ amp. to } E_{rn}$$

From equation (49) on page 148.

$$I_{r1} = 19{,}053\frac{(.983 + j.00558) - (.995 + j.00237)}{13.8 + j31.8} + (211.1 - j166.9)\frac{4.99 + j15.5}{13.8 + j31.8}$$
$$= 105.5 - j61.6$$
$$= 122.2 \text{ amp.}$$
$$T_r I_{r2} = 19{,}053\frac{(.983 + j.00558) - (.972 + j.00642)}{6.78 + j29.7} + (211.1 - j166.9)\frac{4.99 + j15.5}{6.78 + j29.7}$$
$$= 105.6 - j105.3$$
$$= 149.1 \text{ amp.}$$

As a check

$$I_{r1} = 105.5 - j61.6$$
$$T_r I_{r2} = 105.6 - j105.3$$
$$I_r = 211.1 - j166.9$$

$$P_{rn1} + jQ_{rn1} = 19.053(105.5 + j61.6)$$
$$= 2{,}010 + 1{,}174$$
$$P_{rn2} + jQ_{rn2} = 19.053(105.6 + j105.3)$$
$$= 2{,}011 + j2{,}006$$
$$P_{rn} + jQ_{rn} = 4{,}021 + j3{,}180 \text{ kv.a. per phase}$$

Total power at receiving end

$$P_r + jQ_r = 3(4{,}021 + j3{,}180)$$
$$= 12{,}063 + j9{,}540 \text{ kv.a.}$$

which of course, is the same as in Case 2 and checks with the original load assumed.

From equation (5) on page 141

$$E_{gen-n} = 19{,}053(.995 + j.00237) + (105.5 - j61.6)(13.8 + j31.8)$$

or

$$= 19{,}053(.972 + j.00642) + (105.6 - j105.3)(6.78 + j29.7)$$

or

$$= 19{,}053(.983 + j.00558) + (211.1 - j166.9)(4.99 + j15.5)$$
$$= 22{,}367 + j2{,}547$$
$$= 22{,}512 \diagup 6° \; 30' \text{ to } E_{rn}$$
$$I_{s1} = (105.5 - j61.6)(.995 + j.00237) + 19{,}053(0 + j.000341)$$
$$= 105.1 - j54.5 = 118.4 \text{ amp.}$$
$$T_s I_{s2} = (105.6 - 105.3)(.972 + j.00642) + 19{,}053(-.000003 + j.00185)$$
$$= 103.2 - j66.4 = 122.8 \text{ amp.}$$
$$I_{ts} = (1.1 - j9.4)(\cos + j \sin) \; 6° \; 30'$$
$$= 2.2 - j9.3$$
$$T_s I_{gen-2} = 105.4 - j75.7 = 129.8 \text{ amp.}$$
$$I_{s1} = 105.1 - j54.5$$
$$I_{gen} = 210.5 - j130.2$$
$$= 247.5 \diagdown 31° \; 44' \text{ amp. to } E_{rn}$$

As a check, based on the overall constants

$$I_s = (211.1 - j166.9)(.983 + j.00558) + 19{,}053(-.000003 + j.00220)$$
$$= 208.3 - 1j20.9$$
$$I_{ts} = 2.2 - j9.3$$
$$I_{gen} = 210.5 - j130.2$$

Or, from equation (42) on page 147, in terms of terminal voltages

$$I_s = \frac{(22{,}367 + j2{,}547)\dfrac{.983 + j.00558}{4.99 + j15.5} - 19{,}053}{\dfrac{1}{4.99 + j15.5}}$$

$= 208.3 - j120.9$ as above.

$$P_{sn1} + jQ_{sn1} = (22.367 + j2.547)(105.1 + j54.5) = 2{,}211 + j1{,}487$$

$$P_{gen-n2} + jQ_{gen-n2} = (22.367 + j2.547)(105.4 + j75.7) = 2{,}165 + j1{,}961$$

$$P_{gen-n} + jQ_{gen-n} = (22.367 + j2.547)(210.5 + j130.2) = 4{,}376 + j3{,}448 \text{ kv.a. per phase}$$

Total power at the sending end

$$P_{gen} + jQ_{gen} = 3(4{,}376 + j3{,}448) = 13{,}128 + j10{,}344 = 16{,}712 \text{ kv.a.}$$

$$\text{Power loss} = 13{,}128 - 12{,}063 = 1{,}065 \text{ kw.} = 8.84 \text{ per cent of } P_r$$

$$\text{Voltage drop} = 22{,}512 - 19{,}053 = 3{,}459 \text{ volts} = 18.2 \text{ per cent of } E_{rn}.$$

The results of the above complete solution are compared below with those of the impedance solution of Case 2.

	Complete Solution	Impedance Solution
I_{r1}	122.2	127.2
T_rI_{r2}	149.1	143.0
I_{s1}	118.4	127.2
T_sI_{gen-2}	129.8	151.0
I_{gen}	247.5	276.5
E_{gen-n}	22,512.0	22,861.0
P_{gen}	13,128.0	13,239.0
Power loss—kw	1,065.0	1,176.0
Per cent of P_r	8.84	9.75
Voltage drop—volts	3,459.0	3,808.0
Per cent of E_{rn}	18.2	20.0

Case 4

Transformers in One Circuit Having Different Ratios (Complete Solution)

The line and load conditions in this case, as shown in Fig. 96 are identical with those of Case 3, except that in place of equal ratios for the sending and receiving end transformers the sending end transformer is connected on the 10 per cent over-voltage tap, giving a ratio of 2.2 for this transformer. The same diagram is used, the only difference in Case 4 being in the values of the low voltage constants of the transformer circuit and the overall constants. These are as follows:

$$A_{2-lv} = \frac{2}{2.2}(.972 + j.00642) = .884 + j.00583$$

$$B_{2-lv} = \frac{1}{2 \times 2.2}(27.1 + j119) = 6.17 + j27.0$$

$$C_{2-lv} = 2 \times 2.2(-.0000007 + j.000463) = -.000003 + j.00204$$

$$D_{2-lv} = \frac{2.2}{2}(.972 + j.00642) = 1.07 + j.00706$$

It will be noted that with different transformer ratios the circuit referred to low voltage conditions is unsymmetrical and the A and D constants are no longer equal. The change of impedance of the transformers, being very slight, is neglected.

From Network No. 17

$$A = \frac{(.995 + j\,.00237)(6.17 + j27.0) + (13.8 + j31.8)(.884 + j.00583)}{(13.8 + j31.8) + (6.17 + j27.0)} = .933 + j.00940$$

$$B = \frac{(13.8 + j31.8)(6.17 + j27.0)}{(13.8 + j31.8) + (6.17 + j27.0)} = 4.67 + j14.7$$

$$C = (0 + j.000341) + (-.000003 + j.00204) + \frac{\{(.995 + j.00237) - (.884 + j.00583)\}\{(1.07 + j.00706) - (.995 + j.00237)\}}{(13.8 + j31.8) + (6.17 + j27.0)} = .000044 + j.00225$$

$$D = \frac{(13.8 + j31.8)(1.07 + j.00706) + (.995 + j.00237)(6.17 + j27.0)}{(13.8 + j31.8) + (6.17 + j27.0)} = 1.04 + j.00155$$

As in Cases 2 and 3

$$E_{rn} = 19{,}053$$
$$I_r = 211.1 - j166.9$$

From equation (49) on page 148

$$I_{r1} = 19{,}053\frac{(.933 + j.00940) - (.995 + j.00237)}{13.8 + j31.8} + (211.1 - j166.9)\frac{4.67 + j14.7}{13.8 + j31.8} = 91.4 - j31.8 = 96.8 \text{ amp.}$$

$$T_rI_{r2} = 19{,}053\frac{(.933 + j.00940) - (.884 + j.00583)}{6.17 + j27.0} + (211.1 - j166.9)\frac{4.67 + j14.7}{6.17 + j27.0} = 119.7 - j135.1 = 180.4 \text{ amp.}$$

As a check

$$I_{r1} = 91.4 - j\,31.8$$
$$T_rI_{r2} = 119.7 - j135.1$$
$$I_r = 211.1 - j166.9$$

$$P_{rn1} + jQ_{rn1} = 19.053(91.4 + j31.8) = 1{,}742 + j606.$$

$$P_{rn2} + jQ_{rn2} = 19.053(119.7 + j135.1 = 2{,}279 + 2{,}574$$

$$P_{rn} + jQ_{rn} = 4{,}021 + j3{,}180 \text{ kv.a. per phase.}$$

Total power at receiving end

$$P_r + jQ_r = 3(4{,}021 + j3{,}180) = 12{,}063 + j9{,}540 \text{ kv.a.}$$

which, as before, checks with the original load assumed.

$$E_{gen-n} = 19{,}053(.995 + j.00237) + (91.4 - j31.8)(13.8 + j31.8)$$

or

$$= 19{,}053(.884 + j.00583) + (119.7 - j135.1)(6.17 + j27.0)$$

or

$$= 19{,}053(.933 + j.00940) + (211.1 - j166.9)(4.67 + j14.7)$$
$$= 21{,}226 + j2{,}512$$
$$= 21{,}374\underline{/6° \ 45'} \text{ volts.}$$

$$I_{s1} = (91.4 - j31.8)(.995 + j.00237) + 19{,}053(0 + j.00341)$$
$$= 91.0 - j24.9 = 94.4 \text{ amp.}$$
$$T_sI_{s2} = (119.7 - j135.1)(1.07 + j.00706) + 19{,}053(-.000003 + j.00204)$$
$$= 128.8 - j104.8 = 166.1 \text{ amp.}$$

As the transformer ratio has been increased 10 per cent at the sending end we have assumed for simplicity that the exciting current referred to low voltage will be proportionately increased, and

$$I_{ts} = 1.1(1.1 - j9.4)(\cos + j \sin)6° \ 45'$$
$$= 2.4 - j10.2$$
$$T_sI_{gen-2} = 131.2 - j115.0 = 174.5 \text{ amp.}$$
$$I_{s1} = \underline{\ \ 91.0 - j\ 24.9}$$
$$I_{gen} = 222.2 - j139.9$$
$$= 262.6\diagdown 32° \ 11' \text{ amp. to } E_{rn}$$
$$P_{sn1} + jQ_{sn1} = (21.226 + j2.512)(91.0 + j24.9)$$
$$= 1{,}869 + j758$$
$$P_{gen-n2} + jQ_{gen-n2} = (21.226 + j2.512)(131.2 + j115.0)$$
$$= 2{,}497 + j2{,}769$$
$$P_{gen-n} + jQ_{gen-n} = (21.226 + j2.512)(222.2 + j139.9)$$
$$= 4{,}366 + j3{,}527 \text{ kv.a. per phase}$$

Total power at sending end

$$P_{gen} + jQ_{gen} = 3(4{,}366 + j3{,}527)$$
$$= 13{,}098 + j10{,}581$$
$$= 16{,}838 \text{ kv.a.}$$
$$\text{Power loss} = 13{,}098 - 12{,}063$$
$$= 1{,}035 \text{ kw.}$$
$$= 8.58 \text{ per cent of } P_r$$
$$\text{Voltage drop} = 21{,}374 - 19{,}053$$
$$= 2{,}321 \text{ volts}$$
$$= 12.2 \text{ per cent of } E_{rn}.$$

The effect of the higher transformer ratio at the sending end is shown by the following comparison with the results of Case 3.

	Case 3 $T_s = 2$	Case 4 $T_s = 2.2$
I_{r1}	122.2	96.8
T_rI_{r2}	149.1	180.4
I_{s1}	118.4	94.4
T_sI_{gen-2}	129.8	174.5
I_{gen}	247.5	262.6
E_{gen-n}	22,512	21,374
P_{gen}	13,128	13,098
Total power loss—kw	1,065	1,035
Per cent	8.84	8.58
Voltage drop to neutral-volts	3,459	2,321
Per cent	18.2	12.2

HEATING OF BARE CONDUCTORS IN AIR

If the circuit is long, the voltage will probably be high, so that the current will be comparatively small. In this case, the heating effect of the current will be small and unimportant. If, however, the circuit is short and an unusually large amount of power is to be transmitted, the current will be large. Since the I^2R loss varies as the square of the current and directly as the resistance, the heat generated, if the current is large, may be sufficient to overheat or anneal the material of the conductor.

Tests indicate that both copper and aluminum conductors start to anneal at a temperature not far above 100°C. For this reason, particularly where mechanical strength is a factor, such as for long spans in transmission lines, current densities should be kept low enough so that a 100°C. total temperature is not exceeded. The idle conductor for the hottest days of the summer may reach a temperature of 60°C. due to the high air temperature in conjunction with the absorbed radiations from the sun; this will permit a temperature rise of 40°C. due to the heating of the load current.

Tests for determining the temperature rise of conductors suspended in still air have sometimes yielded values differing widely. Formulae published in some of the older editions of hand books for determining these temperature rises differ materially. The cause of these unsatisfactory results is the difficulty of making such temperature measurements. A very slight movement of air surrounding the conductor on test will greatly reduce the temperature rise. George E. Luke, as the result of a large number of carefully made tests upon various sizes of cables and wires in still air, has derived the following formula for determining the temperature rise:

Since the loss $I^2R = \pi dLK_dT$

$$I = \sqrt{\frac{\pi dLK_dT}{R}}$$

Where I = continuous current capacity in still air, in amperes
d = outside diameter of bare cable in inches
L = length of cable in inches
K_d = dissipation constant obtained from Fig. 97
T = degrees C. continuous temperature rise of the cable
R = resistance of the cable (length L) at its continuous temperature (T plus air temperature).

The values in the accompanying table, "Heating Capacity for 40°C. Rise," were derived by the above formula. The current values for 40°C. rise above air at 25°C. (total 65°C.) have been expressed in the form of kv.a., three-phase values corresponding to various transmission voltages. Thus No. 0000 stranded bare copper conductors suspended in still air out of doors at 25°C. (77°F.) will carry 320 amp. with a temperature rise of 40°C. (total temperature 65°C. —149°F.). If the transmission voltage is 220 volts, the corresponding kv.a. value will be 120 kv.a., three-phase and if the transmission voltage is 11,000 volts, 6,100 kv.a. three-phase may be transmitted with the same temperature rise. In calculating the table values dissipation constants corresponding to conductors having bright

surfaces as given by the curves of Fig. 97 were assumed.

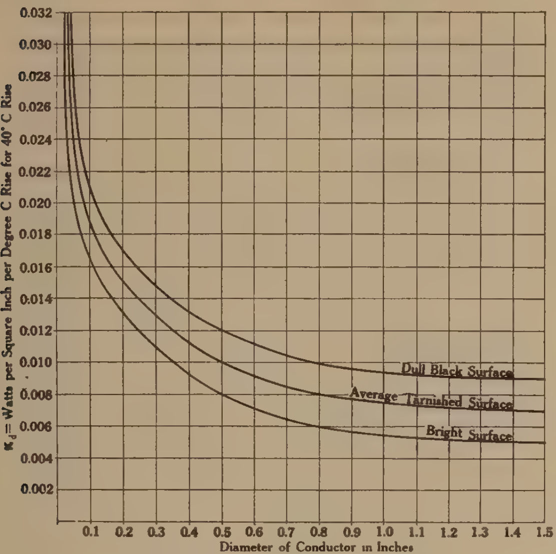


FIG. 97.—Luke's dissipation constants.

To illustrate, No. 0000 stranded bare copper conductor has a diameter of .522 inches. The curve corresponding to bright surfaces in Fig. 97 shows the dissipation constant to be .0077,

$$I = \sqrt{\frac{\pi \times .522 \times 63{,}360 \times .0077 \times 40}{.311}} = 320 \text{ amp.}$$

approximately

The numerals used correspond to a length of one mile.

As indicated, the curves of Fig. 97 are based upon a temperature rise of 40°C. For other temperature rises the values read from the curves must be *multiplied* by the factor $\sqrt[4]{T/40}$. For instance, if a temperature rise of 50°C. is permissible, we have $\sqrt[4]{50/40}$ or 1.055 and K_d as read from the curves must be multiplied by 1.055.

It is interesting to note that an insulated cable may have more current carrying capacity than the same conductor bare. This is for the reason that the decrease in the surface temperature drop by the increased diameter, due to the addition of the insulation may more than neutralize the small increase in temperature drop necessary to conduct the heat through the insulation.

HEATING CAPACITY FOR 40°C. RISE

FOR BARE CONDUCTORS WITH BRIGHT SURFACE (SUSPENDED IN STILL AIR).

SIZE OF CONDUCTOR		OUTSIDE DIAMETER IN INCHES	AMPERES FOR 40° C. RISE	APPROXIMATE CARRYING CAPACITY IN KV-A, THREE PHASE, CORRESPONDING TO THE AMPERES IN COLUMN HEADED "AMPERES FOR 40° C RISE"									
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S		★	220 VOLTS Kv-A	440 VOLTS Kv-A	550 VOLTS Kv-A	2200 VOLTS Kv-A	4000 VOLTS Kv-A	6600 VOLTS Kv-A	11000 VOLTS Kv-A	22000 VOLTS Kv-A	33000 VOLTS Kv-A	66000 VOLTS Kv-A
HARD DRAWN COPPER—97.3% CONDUCTIVITY													
2 000 000		1.631	1250	475	950	1180	4750	8630	14 260	23 700	47 500	71 300	142 600
1 900 000		1.590	1210	460	920	1150	4600	8360	13 800	23 000	46 000	69 000	138 000
1 800 000		1.548	1175	445	890	1110	4460	8100	13 400	22 300	44 600	67 000	134 000
1 700 000		1.504	1135	430	860	1080	4320	7850	12 950	21 600	43 200	64 700	129 500
1 600 000		1.459	1090	415	830	1030	4130	7500	12 400	20 600	41 300	62 000	124 000
1 500 000		1.412	1045	400	800	990	3970	7200	11 900	19 800	39 700	59 500	119 000
1 400 000		1.364	1010	385	770	950	3830	6950	11 500	19 100	38 300	57 500	115 000
1 300 000		1.315	970	370	740	920	3700	6750	11 100	18 500	37 000	55 500	111 000
1 200 000		1.263	930	355	710	880	3530	6450	10 600	17 600	35 300	53 000	106 000
1 100 000		1.209	860	330	660	810	3260	5950	9 800	16 300	32 600	49 000	98 000
1 000 000		1.152	810	310	620	770	3080	5600	9 250	15 400	30 800	46 200	92 500
950 000		1.123	795	300	600	750	3020	5500	9050	15 100	30 200	45 200	90 500
900 000		1.093	765	290	580	730	2920	5300	8 750	14 600	29 200	43 700	87 500
850 000		1.062	735	280	560	700	2800	5100	8 400	14 000	28 000	42 000	84 000
800 000		1.031	705	270	540	670	2680	4900	8 050	13 400	26 800	40 200	80 500
750 000		.998	685	260	520	650	2600	4700	7 800	13 000	26 000	39 000	78 000
700 000		.964	655	250	500	620	2480	4500	7 450	12 400	24 800	37 200	74 500
650 000		.929	625	240	480	590	2360	4300	7 100	11 800	23 600	35 500	71 000
600 000		.891	600	230	460	570	2280	4150	6 850	11 400	22 800	34 200	68 500
550 000		.853	560	215	430	530	2130	3900	6 400	10 600	21 300	32 000	64 000
500 000		.814	530	200	400	500	2020	3680	6 050	10 100	20 200	30 200	60 500
450 000		.772	495	190	380	490	1880	3400	5 650	9 900	18 800	28 200	56 500
409 000		.725	460	175	350	440	1750	3180	5 250	8 750	17 500	26 200	52 500
350 000		.679	420	160	320	400	1600	2920	4 800	8 000	16 000	24 000	48 000
300 000		.628	390	150	300	370	1480	2700	4 450	7 400	14 800	22 200	44 500
250 000		.574	350	135	270	330	1330	2400	4 050	6 650	13 300	20 000	40 000
211 600	0 000	.522	320	120	240	300	1220	2200	3 650	6 100	12 200	18 200	36 500
167 806	000	.464	280	105	210	260	1060	1930	3 200	5 300	10 600	16 000	32 000
133 077	00	.414	240	90	180	230	910	1660	2 740	4 550	9 100	13 700	27 400
105 535	0	.368	210	80	160	200	800	1450	2 400	4 000	8 000	12 000	24 000
83 693	1	.328	180	68	136	170	680	1230	2 050	3 410	6830	10 200	20 500
66 371	2	.292	160	61	122	150	607	1100	1 820	3 030	6070	9 100	18 200
52 635	3	.260	140	53	106	130	530	960	1 600	2 650	5 300	8 000	16 000
41 741	4	.232	120	46	92	110	455	830	1 370	2 280	4 560	6 850	13 700
33 102	5	.206	102	42	84	96	385	700	1 160	1 930	3 860	5 800	11 600
26 251	6	.184	87	33	66	82	330	600	990	1 650	3 300	4 950	9 900
ALUMINUM CABLE STEEL REINFORCED													
1 590 000		1.544	1000	380	760	950	3 800	6 900	11 400	19 000	38 000	57 000	114 000
1 510 500		1.506	970	370	740	920	3 700	6 750	11 100	18 500	37 000	55 000	111 000
1 431 000		1.465	930	353	706	880	3 530	6 450	10 600	17 600	35 300	53 000	106 000
1 351 500		1.424	900	340	680	850	3 400	6 200	10 200	17 000	34 000	51 000	102 000
1 272 000		1.382	860	325	650	810	3 260	5 950	9 800	16 300	32 600	49 000	98 000
1 192 500		1.337	830	315	630	790	3 160	5 750	9 500	15 800	31 600	47 500	95 000
1 113 000		1.292	790	300	600	750	3 000	5 450	9 000	15 000	30 000	45 000	90 000
1 033 500		1.246	755	285	570	710	2 860	5 200	8 600	14 300	28 600	43 000	86 000
954 000		1.196	710	270	540	670	2 700	4 900	8 100	13 500	27 000	40 500	81 000
900 000		1.162	680	260	520	650	2 600	4 750	7 800	13 000	26 000	39 000	78 000
874 500		1.146	670	255	510	630	2 530	4 600	7 600	12 600	25 300	38 000	76 000
795 000		1.093	630	240	480	600	2 400	4 350	7 200	12 000	24 000	36 000	72 000
715 500		1.036	585	220	446	550	2 230	4 050	6 700	11 100	22 300	33 500	67 000
666 600		1.000	555	210	424	530	2 120	3 850	6 350	10 600	21 200	31 700	63 500
636 000		.977	535	200	406	500	2 030	3 700	6 100	10 100	20 300	30 500	61 000
605 000		.953	520	198	396	490	1 980	3 600	5 950	9 900	19 800	29 700	59 500
556 500		.953	500	190	380	480	1 900	3 460	5 700	9 500	19 000	28 500	57 000
556 500		.912	495	188	376	470	1 880	3 420	5 650	9 400	18 800	28 200	56 500
518 000		1.000	500	190	380	480	1 900	3 460	5 700	9 500	19 000	28 500	57 000
500 000		.904	470	178	356	440	1 780	3 240	5 350	8 900	17 800	26 700	53 500
477 000		.883	455	173	346	430	1 730	3 150	5 200	8 600	17 300	26 000	52 000
477 000		.845	445	170	340	420	1 700	3 100	5 100	8 500	17 000	25 500	51 000
397 500		.806	405	153	306	380	1 530	2 800	4 600	7 600	15 300	23 000	46 000
397 500		.771	400	152	304	380	1 520	2 760	4 550	7 600	15 200	22 700	45 500
336 400		.741	365	138	276	340	1 380	2 520	4 150	6 900	13 800	20 700	41 500
336 400		.710	355	135	270	330	1 350	2 460	4 050	6 700	13 500	20 200	40 500
300 000		.700	340	130	260	320	1 300	2 360	3 900	6 500	13 000	19 500	39 000
300 000		.670	335	126	252	310	1 260	2 300	3 800	6 300	12 600	19 000	38 000
266 800		.632	315	120	240	300	1 200	2 180	3 600	6 000	12 000	18 000	36 000
266 800		.633	305	116	233	290	1 160	2 120	3 500	5 800	11 600	17 500	35 000
211 600	0 000	.564	265	100	200	250	1 000	1 820	3 000	5 000	10 000	15 000	30 000
167 806	000	.501	235	90	180	220	900	1 640	2 700	4 500	9 000	13 500	27 000
133 077	00	.447	205	78	156	190	780	1 420	2 350	3 900	7 800	11 700	23 500
105 535	0	.398	180	69	138	170	690	1 250	2 060	3 450	6 900	10 300	20 600
83 693	1	.355	160	61	122	150	610	1 110	1 830	3 050	6 100	9 100	18 300
66 371	2	.316	135	51	102	130	510	930	1 540	2 550	5 100	7 700	15 400
52 635	3	.281	120	46	92	110	460	830	1 370	2 300	4 600	6 800	13 700
41 741	4	.250	105	40	80	100	400	730	1 200	2 000	4 000	6 000	12 000
33 102	5	.223	90	34	68	85	340	620	1 030	1 700	3 400	5 100	10 300
26 251	6	.198	75	28	56	70	280	515	850	1 400	2 800	4 200	8 500

★ The table values were calculated by Mr. Luke's formula as given in the text.

CHAPTER XIX

STABILITY OF TRANSMISSION LINES

Before discussing stability of transmission lines, it may be desirable to review how a change in power-factor affects the generators supplying the current.

Figure 98 shows the effect of in-phase, lagging and leading components of armature current upon the field strength of generators.* A single-coil armature is illustrated as revolving between the north and south poles of a bilpolar alternator. The coil is shown in four positions 90 degrees apart, corresponding to one complete revolution of the armature coil. The direction of the field flux is assumed to be constant as indicated by the arrows on the field poles of each illustration. In addition to this field flux, when current flows through the armature coil another magnetic flux is set up, magnetizing the iron in the armature in a direction at right angles to the plane of the armature coil. This will be referred to as armature flux.

This armature flux varies with the armature current, being zero in a single-phase generator when no armature current flows, and reaching a maximum when full armature current flows. It changes in direction relative to the field flux as the phase angle of the armature current changes.

The revolving armature coil generates an alternating voltage the graph of which follows closely a sine wave, as shown in Fig. 98. When it occupies a vertical plane marked *start* no voltage is generated, for the reason that the instantaneous travel of the coil, is parallel with the field flux.† As the coil moves forward in a clockwise direction, the field enclosed by the armature coil decreases; at first slowly but then more rapidly until the rate of change of flux through the coil becomes a maximum when the coil has turned 90°, at which instant the voltage generated becomes a maximum. As the horizontal position is passed the voltage decreases until it again reaches zero when the coil has traveled 180° or occupies again a vertical plane. As the travel continues the voltage again starts to increase but since the motion of the coil relative to the fixed magnetic field is reversed the voltage in the coil builds up in the reverse direction during the second half of the revolution. When the coil has reached the 270 degree position the voltage has again become maximum but in the opposite direction to that when the coil occupied the position of 90°. When the coil returns to its original position at the start the voltage has again dropped to zero, thus completing one cycle.

If the current flowing through this armature coil is in phase with the voltage, it will produce cross magnetization in the armature core, in a vertical direction, as indicated by the arrows at the 90° and 270° positions. The cross magnetization neither opposes nor adds to the field flux at low loads and therefore has comparatively little influence on the field flux. At heavy loads, however, this cross magnetization has considerable demagnetizing effect, due to the shift in rotor position resulting from the shifting of the field flux at heavy loads.

If the armature is carrying lagging current, this current will tend to magnetize the armature core in such a direction as to oppose the field flux. This action is shown by the middle row of illustrations of Fig. 98. Under these illustrations is shown a current wave lagging 90° representing the component of current required to magnetize transformers, induction motors, etc. When the lagging component of current reaches its maximum value the armature coil will occupy a vertical position (position marked start, 180° and 360°) and in this position the armature flux will directly oppose the field flux, as indicated by the arrows. The result is to reduce the flux threading the armature coil and thus cause a lowering of the voltage. This lagging current encounters resistance and a relatively much greater reactance, each of which consumes a component of the induced voltage, as shown in Fig. 98. When the armature current is lagging, the voltage induced by armature inductance is in such a direction as to subtract from the induced voltage, and thus the voltage is still further lowered, as a result of the armature self induction. In order to bring the voltage back to its normal value it will be necessary to increase the field flux by increasing the field current. Generators are now usually designed of sufficient field capacity to compensate for lagging loads of 80 per cent power-factor.

If the armature is carrying a leading current this leading component will tend to magnetize the armature core in such a direction as to add to the field flux. This action is shown by the bottom row of illustrations of Fig. 98. Under these illustrations is shown a current wave leading the voltage wave by 90°. When the leading component of current reaches its maximum values, the armature coil will again occupy vertical

* For a more detailed discussion of this subject the reader is referred to excellent articles by F. D. Newbury in the Electric Journal of April, 1918, "Armature Reaction of Polyphase Alternators;" and of July, 1918, "Variation of Alternator Excitation with Load."

† For the sake of simplicity this and the following statements are based upon the assumption that armature reaction does not shift the position of the field flux. Actually, under load, the armature reaction causes the position of the field flux to be shifted toward one of the pole tips, so that the position of the armature coil is not quite vertical at the instant of zero voltage in the coil.

positions, but the armature flux will add to that of the field flux, as indicated by the arrow. The resulting flux threading the armature coil is thus increased causing a rise in voltage. This leading current flowing through the generator armature encounters resistance and a relatively much greater reactance, each of which consumes a component of the induced voltage, as shown in Fig. 98. When the armature current is leading, the voltage induced by armature inductance is in such a direction as to add to the induced voltage and thus the voltage at the alternator terminals is still further increased as the result of armature self-induction. In order to reduce the voltage to its normal value it is necessary to decrease the field flux by decreasing the field current.

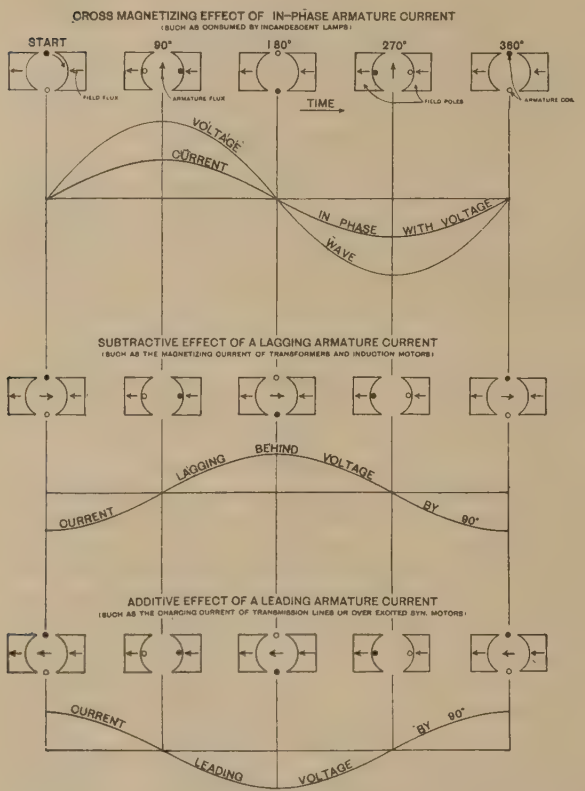


FIG. 98.—Effect of armature current upon field excitation of alternating-current generators.

With alternators of high reaction the magnetizing or de-magnetizing effect of leading or lagging current will be greater than in cases where the armature reaction is low. For instance if the alternator is so designed that the ampere turns of the armature at full armature current are small compared to its field ampere turns, the voltage of such a machine would be less disturbed with a change in power-factor of the armature current than in an alternator having armature ampere turns large compared with its field ampere turns.

Modern alternators are of such design that when carrying rated lagging current at zero power-factor they require approximately 200 to 250 per cent of their no-load field-current and when carrying rated leading current at zero power-factor they require approximately -15 to $+15$ per cent of their no-load field current. Thus with lagging armature current the iron will be worked at a considerable higher point on the saturation curve and the heating of the field coils will increase because of the greater field current required.

The voltage diagrams of Fig. 99 are intended to show only the effect of armature resistance and armature reactance upon voltage variation. Voltage regulation is the combined effect of armature impedance and armature reaction. Turbogenerators have, for instance, very low armature reactance but their armature reaction is higher, so that the resulting voltage regulation may not be materially different from that of a machine with double the armature reactance. Under normal operation armature reaction is a more potent factor in determining the characteristics of a generator than armature reactance. In the case of a generator with a short circuit ratio of unity, this total reactive effect may be due, 15 per cent to armature reactance and 85 per cent to armature reaction.

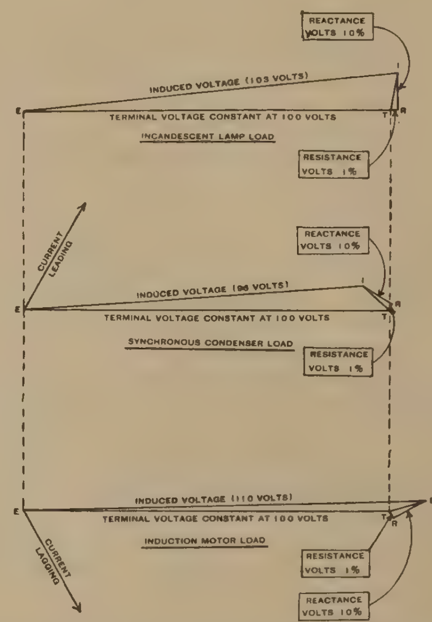


FIG. 99.—Vectors illustrating the effect of armature reactance and resistance upon the terminal voltage for in-phase, leading and lagging currents.

For the case illustrated by Fig. 99 the field flux corresponds to the induced voltage indicated, but the field current does not. The field current corresponds to a value obtained by substituting the full synchronous impedance drop for that indicated.

BEHAVIOR OF A.-C. GENERATORS WHEN CHARGING A TRANSMISSION LINE*

It has been shown above how leading armature current, by increasing the field strength, causes an increase in the voltage induced in the armature of an alternator and consequently an increase in its terminal voltage. It was also shown that the terminal voltage is further increased as result of the voltage due to self induction adding vectorially to the voltage induced in the armature.

If an alternator with its fields open is switched onto a dead transmission line having certain electrical characteristics, it will become self exciting, provided there is sufficient residual magnetism present to start the phenomenon. In such case, the residual magnetism in the fields of the generator will cause a low voltage to be generated which will cause a leading line charging current to flow through the armature. This leading current will increase the field flux which in turn will increase the voltage, causing still more charging current to flow, which in turn will still further increase the line voltage. This building up will continue until stopped by saturation of the generator fields. This is the point of stable operation. Whether or not a particular generator becomes self exciting when placed upon a dead transmission line depends upon the relative slope of the generator and line characteristics.

In Fig. 100 are shown two curves for a single 45,000 kv.a., 11,000 volt generator, the charging current of the transmission line being plotted against generator terminal voltage. One curve corresponds to zero excitation, the other curve to 26.6 per cent of normal excitation. A similar pair of curves correspond to two duplicate generators in parallel.† The straight line representing the volt-amp. characteristics of the transmission line fed by these generators corresponds to a 220 kv., 60 cycle, three-phase transmission circuit, 225 miles long, requiring 69,000 kv.a. to charge it with the line open at the receiving end.

The volt-amp. charging characteristic of a transmission line is a straight line, that is, the charging current is directly proportional to the line voltage. On the other hand the exciting volt-amp. characteristic for the armature has the general slope of an ordinary saturation curve.

If the alternator characteristic lies above the line characteristic at a point corresponding to a certain charging current, the leading charging current will cause a higher armature terminal voltage than is required to produce that current on the line. As a result the current and voltage will continue to rise until, on account of saturation, the alternator characteristic falls until it crosses the line characteristic. At this point the voltage of the generator and that of the line are the same for the corresponding current. If on the other hand the alternator characteristic falls below the line characteristic the alternator will not build up without permanent excitation.

As stated previously, whether or not a generator becomes self-exciting when connected to a dead transmission line depends upon the relative slopes of generator and transmission line characteristics. The relative slopes of these curves depend upon:

a—The magnitude of the line charging current.
b—The rating of the generators compared to the full voltage charging kv.a. of the line.
c—The armature reaction. High armature reaction, (that is low short-circuit ratio) favors self-excitation of the generators.
d—The armature reactance. High armature reactance also favors self-excitation of the generators.

Methods of Exciting Transmission Lines.—If the relative characteristics of an alternator and line are such as to cause the alternator to be self-exciting, this condition may be overcome by employing two or more

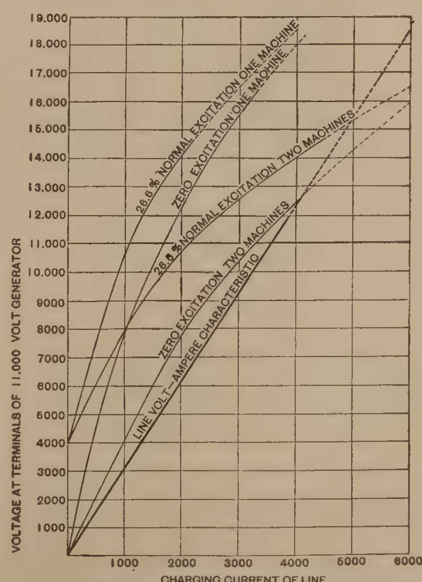


FIG. 100.—Volt amp. characteristics of one 45,000 kv.a., 11,000 volt generator; two duplicate 45,000 kv.a. generators; and a three-phase, single-circuit, 220 kv. transmission line.

alternators (provided they are available for this purpose) to charge the transmission line. The combined characteristics of two or more alternators may be such as to fall under the line characteristic, in which case the alternator will not be self-exciting. In such case, the alternators could be brought up to normal speed, and given sufficient field charge to enable them to be synchronized and held in step, after which they could

* For a more detailed discussion of this subject see the following articles: "Characteristics of Alternators When Excited by Armature Currents" by F. T. Hague in the ELECTRIC JOURNAL for August, 1915; "The Behavior of Alternators with Zero Power-factor Leading Current" by F. D. Newbury, in the ELECTRIC JOURNAL for September, 1918; "The Behavior of A.-C. Generators When Charging a Transmission Line" by W. O. Morris, in the GENERAL ELECTRIC REVIEW for February, 1920.

† It is assumed that with the assumed field current such generators can be synchronized and held together during the process of charging the line.

be connected to the dead transmission line and their voltage raised to normal.

Generators as normally designed will carry approximately 40 per cent of their rated current at zero leading power-factor. If more than this current is demanded of them they are likely to become unstable in operation. By modifying the design of normal alternators so as to give low armature reaction, they may be made to carry a greater percentage of leading current. If the special design is such that with zero voltage field excitation when carrying half the line charging kv.a., the armature voltage will not exceed 70 per cent of normal, this reduced voltage will result in a line charging kv.a. of half of normal value. Specially designed alternators usually result in larger and more costly machines and the gain resulting in the special design is usually not sufficient to warrant the extra cost.

If a single generator with its field circuit open were connected to a dead transmission circuit such as the one whose volt-amp. characteristics are shown in Fig. 62*a*, and there were sufficient residual magnetism to start the phenomenon, the generator voltage would rise to approximately double normal value before the point of stable operation is reached. If, however, two generators having 26.6 per cent of normal excitation were paralleled and connected to this circuit, a point of stable operation would be reached at a terminal voltage of approximately 15,500 volts. Actually stable operation would be reached at a somewhat less terminal voltage for the reason that the line would probably not be open at the receiving end, but would probably have the lowering transformers connected to it. In such case the magnetizing current required for lowering transformers would lower the receiving end voltage, resulting in less line charging current.

In either case the curves of Fig. 100 show that, either more than two generators will be required to charge the line when unloaded, or some other method of charging must be resorted to. Reactance coils could be used at the receiving end to furnish lagging current for neutralizing some of the line charging current, but there might be difficulty in removing these from the circuit when the line is fully charged. At the present time it is expected that the problem of charging long transmission lines may usually be solved by starting one or more generators with sufficient field strength to permit them to be synchronized and held in step. One or more phase modifiers with under-excited fields may then be connected to the line at the receiving end and brought up to normal speed with the generators. Such a method of solving this problem has been employed by the Southern California Edison Company.

LONG LINES WITH LIGHT LOAD

Occasionally a line is built to transmit ultimately a large block of power but to be operated initially with a comparatively small power load. On account of the relatively large line charging current as compared with the power load the power factor of the generator load may be leading even when the maximum power load is being carried. This requires a machine designed for very stable operation at leading power factors as well as for operation at lagging power factors when the ultimate load builds up on the line. For a machine to deliver power under leading power factor operation requires that it be designed for more stability, than when merely charging the line, to insure that it will not pull out of step on account of the torque it must develop. To increase the stability of generators supplying leading current the field strength must be increased with respect to that of the armature so that the effect of the leading current in the armature on the field will be minimized. In order to avoid the large, extra expense of a special generator to meet such operating conditions Mr. M. W. Smith* has suggested the possibility of a cheaper generator of normal design with some special connection of the armature winding, such as an inter-connected star. During the period of light load on the line with such a connection the two half windings of each leg of the star have voltage generated in them 120 degrees displaced from each other. This gives (for a given field strength) a terminal voltage of 86.7 per cent of that for a straight star connection. The greater field strength required to get the same terminal voltage with the inter-connected star connection, provides greater stability and at the same time reduces the demagnetizing effect of the armature current.

REDUCTION IN LOAD

If a large load is suddenly dropped, such as by opening a circuit breaker, and, particularly if this load is at the far end of a long transmission line, a dangerous rise in voltage may result. If the entire generator load is dropped from the bus (no transformer intervening with no transmission line in circuit) the following will happen.

A. The bus voltage will (for a lagging load) instantly rise to that of the induced voltage in the generator winding; since the impedance drop of the armature winding disappears. If the load is leading the voltage will fall as indicated by Fig. 99. Obviously the voltage rise will increase with the amount of load dropped, with lower lagging power factor loads and with the generator having high armature reactance and high voltage regulation.

B. The sudden dropping of full load will cause the generator to speed up momentarily. If the prime mover is a steam turbine the momentary overspeed may be anywhere between, approximately 4 per cent for small, up to 10 per cent for large capacity units. If the prime mover is a water wheel the momentary increase in speed may be from 25 to 35 per cent increase, depending upon the type of wheel, and type and adjustment of governor, length of flume, etc. As a result of this momentary overspeeding the voltage will rise by an amount corresponding to the overspeed.

C. If the generator excitation comes from a direct connected exciter or from an exciter driven by a motor

* See his article referred to in the bibliography at the end of the chapter.

receiving its driving power from the generator it excites, the exciter speed will increase proportionally to the overspeed of the generator. This overspeed of the exciter will cause an increase in excitation and consequently of voltage, which for unsaturated exciter and generator fields will be nearly proportional to that of the overspeed.

D. Voltage regulators, over-voltage and over-speed devices will act to keep down the over-voltage.

If the load dropped is at the high voltage side of the raising transformers with the transmission line open, an additional consideration enters into the matter of over-voltage. In this case the magnetizing current of the raising transformers flows through the generator stator tending to demagnetize its fields. Although this transformer magnetizing component is small (usually 4 to 10 per cent) at normal voltage it increases rapidly, as the voltage goes above normal, particularly in transformers employing silicon steel. This transformer magnetizing current for a normally designed transformer increases something like the following:

Voltage Per Cent	Magnetizing Current Per Cent
100	4
110	10
120	25
130	60
140	170
150	450

From this, it is seen, an over-voltage of approximately 35 per cent will circulate the full transformer rating at zero lagging through the generator stator. The field demagnetizing effect of this will act to limit the value of over-voltage, depending upon the design of the particular generators.

If the load dropped is at the load end of the transmission line and the load transformers are disconnected from the line, a further consideration enters into the matter of over-voltage. This is the effect of the transmission line. If the line is short its effect will be negligible. If, however, the line is very long, particularly if the frequency is 60 cycles, the effect of the charging current of the line must be considered. In this case the rise in generator voltage, and consequently in the line voltage will cause the line to require more charging current. This increasing charging current flowing through the generator stator magnetizes the resultant field strength and still further increases the voltage. If the line is normally operated at near its critical voltage, based upon corona effect the corona loss will increase rapidly with increase in voltage and this will act to hold down the voltage of the generators.

If the load dropped is at the low voltage side of the load transformers so that the load transformers remain energized from the line, an additional factor enters into the question of over-voltage. In this case the increased magnetizing current of the load transformers flows over the line tending to reduce the line voltage as well as acting to demagnetize the fields of the generators. The charging kv.a. of the line increases as the square of the voltage, whereas the magnetizing current of the raising and lowering transformer, although differing greatly in individual design, goes up in general, somewhat as indicated by the tabulation above.

INCREASE IN LOAD

When a transmission line is called upon to deliver a sudden increase in the load the voltage drops momentarily. Voltage regulators, acting through the fields of the exciters of the generators and of phase modifiers, and, some times, through operating motors of induction regulators, act to bring the voltage back to normal. This action is retarded because of the time lag accompaning mechanical operations and also by the comparatively longer time lag accompanying changes in current in inductive circuits, such as the fields of machines.

If the time required to restore normal voltage exceeds a certain value (depending upon existing conditions) some, or all of the synchronous apparatus operating on the system may fall out of step. The synchronous apparatus most fully loaded at the time will be the most likely to fall out of step and shut down. The greater the drop in voltage at the terminals of the synchronous apparatus the greater will be the tendency for it to fall out of synchronism.

In addition to the momentary drop in voltage there is another condition tending to produce unstable conditions. That is: When the load increases, the line and transformer impedance triangles increase in size thus shifting the voltage at the load in phase as well as in value. That is, the addition of load will cause an increase in the phase angles between the rotors of synchronous machines at the two ends of a line, which angle will be greater, the greater the line impedance. This shift in phase of the load voltage causes the synchronous apparatus to fall out of synchronism, but if the regulating devices bring the voltage back to normal quickly enough the synchronous apparatus may pull back into step. If the voltage regulating devices bring the voltage back so that it "overshoots," the greater voltage will aid the machines pulling into step. Since the torque varies as the square of the voltage, the importance of voltage changes will be evident.

During the transient condition while moving from one steady-state position to another steady state position at a different angle there is a mechanical transient due to the inertia of the system which will tend to cause the rotor position to over-shoot the new position of equilibrium and which may result in loss of synchronism.

If it were possible to build voltage regulating devices which were capable of maintaining constant voltage under all load changes, the line itself could be made stable up to its maximum capacity. Even under such impossible, but ideal, conditions as regards voltage maintenance there will still remain other influences tending to instability of the system, such

as shifting of the voltage phase at load centers due to load changes. In cases of other generating plants operating in parallel, difficulty might be experienced in holding these plants in synchronism under large shifting loads, particularly if the plants are separated by a considerable electrical distance.

The conditions which tend to instability are as follows:

A. Large blocks of load taken on suddenly—the greater the increase in load the greater the voltage drop, and, therefore, the greater time required to restore normal voltage. The greater the change in load, the greater the shifting of the phase at the load end due to the impedance drop. The synchronous apparatus must follow reasonably close to the shifting of the phase of the voltage at its terminals. Of course, it cannot follow exactly in step, but if the time the synchronous machine is out of step with the load voltage is very short, the "over-shooting" of the voltage due to the activity of the voltage regulator may be sufficient to pull the machine into step. Naturally the greater the speed at which the additional load is taken on, the less the ability of the regulating devices to keep up with the voltage changes. It should be noted that load increases, so far as the transmission line is concerned, may arise from either the usual increase in load at the receiving end, or from the sudden loss of generating capacity at the receiving end as caused by the operation of an automatic breaker.

B. The switching operations most likely to cause instability are those involving the switching out of a parallel line under load. The transients due to load increases and due to switching operations are similar in that they both will require changes in phase angles of the system, and will involve the mechanical transients mentioned above. The transients due to short circuits may be of two kinds: (1) Those involving a low-resistance short circuit in which the generator would tend to overspeed and thus pull out of synchronism, and (2) those involving a high-resistance short circuit in which the generator would tend to slow down until the faulty section of line was cleared, after which the generator would tend to overspeed and thus pull out of synchronism.

C. Other factors are: high series impedance; high capacity (which reduces excitation of machines); poor inherent characteristics of machines, that is, high reactance, strong armature and weak field; and slow regulators. Then of course the nature of transient disturbances, time required for relay and circuit breaker operations are factors.

Although various conditions contribute to stability the most practical and effective manner of improving the stability of a line is through accelerating the voltage regulating devices.

Synchronous condensers by serving to maintain constant voltage exert an important influence upon system stability. This influence, however, extends only up to the capacity of the condensers to furnish leading reactive power. For this reason, if the line is to be operated near its ultimate capacity, consideration should be given to choosing a condenser of sufficient capacity for stability rather than simply for voltage maintenance under certain load conditions.

Synchronous condensers normally designed for leading power factor operations can carry about 50 per cent of their rating capacity lagging. By special design they may be made to carry their full leading rating lagging. Such a condenser costs more than if designed for full rating only in either leading or lagging range, but is more stable and advantageous when extreme overloads are required on a system operating near the pullout point.

The subject of stability is so much involved, particularly in regard to interconnected networks that it is not intended to give in the above any more than a very elementary idea of the principal elements involved in stability of a single line. The following list of contributions contains much data pertinent to this subject. No doubt there will be numerous valuable papers and discussions from time to time as our knowledge increases upon this much involved subject.

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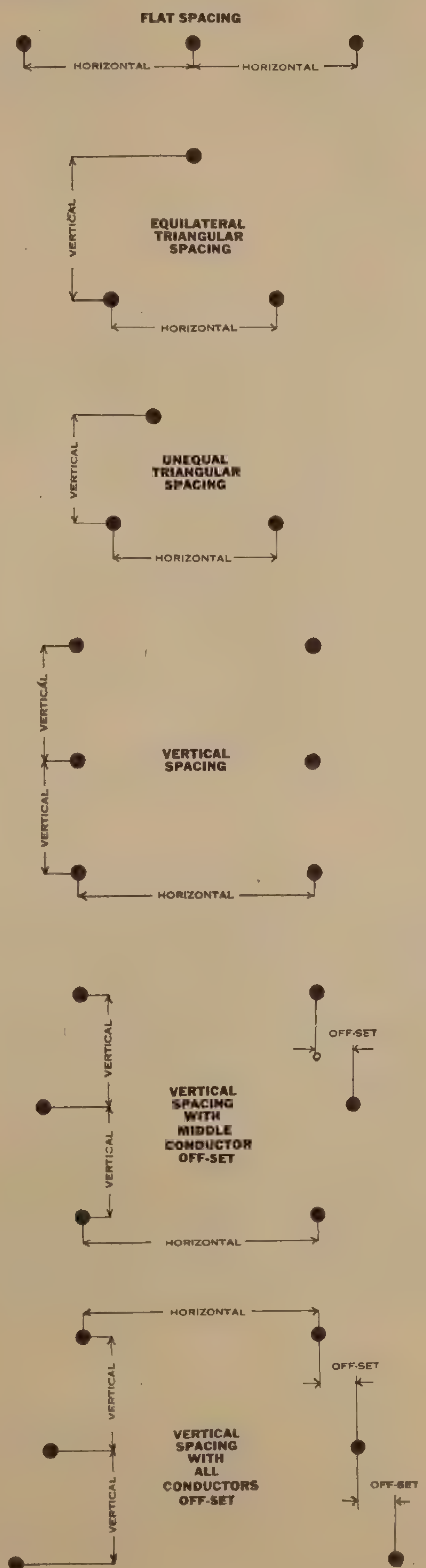
CHAPTER XX

DATA ON HIGH VOLTAGE LINES—SPACING OF CONDUCTORS—TRANSPOSITIONS

DATA ON HIGH VOLTAGE LINES

The data included in the following tabulations has, been partly taken, by permission of the *Electrical World*, from a tabulation of 777 lines published by them in a supplement to their January 25th, 1925, issue; partly from a publication of the Aluminum Company of America of June, 1923, entitled "Aluminum Conductors—Typical Installations;" and partly furnished direct by power companies. An attempt has been made to include the more important and the recently constructed lines. Since most transmission companies usually have more than one line, the terminals of the particular line, or that part of the line covered by the tabulation, is specified for identification. The N. E. L. A. Committees on "Overhead Systems" and the corresponding N. E. L. A. Handbook contain much useful data upon this general subject.



SPACINGS OF CONDUCTORS

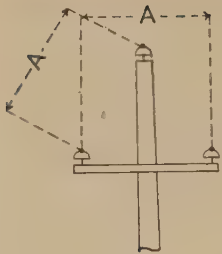
The accompanying sketch will serve to make clear the normal arrangement and spacing of conductors as covered by the tabulations. By "normal" is meant the practices on standard towers and standard span lengths. The practice for maximum spans naturally may be different.

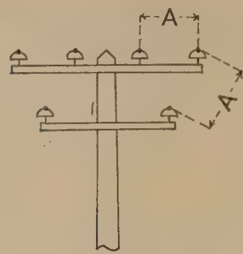
The Aluminum Company of America have worked up recommended approximate spacings for A. C. S. R. Aluminum Conductors, based upon data obtained from successfully operated lines. These are given, with their permission, below. They are, of course, capable of variation one way or another. Although these recommended spacings are based upon A. C. S. R. Aluminum Conductors, it is believed that the horizontal spacings are suitable also for copper conductors. The vertical spacings are, however, regardless of the material of the conductor, determined by an investigation of the behavior of the materials for the weather conditions assumed to exist for the line being investigated. If the line is to be built where there is sleet, the relation of one conductor to the conductor below it will have to be investigated for a temperature around the freezing point when one conductor has a load of ice and the other conductor has not. For long span work, the vertical spacing between A. C. S. R. conductors may differ from copper, taking into account these conditons. In making the calculations it is very important to take into account the actual temperature rise of the conductor carrying a certain load.

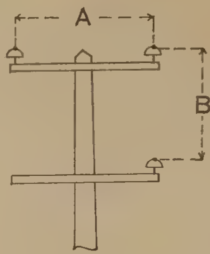
Spacing with Pin Type Insulators

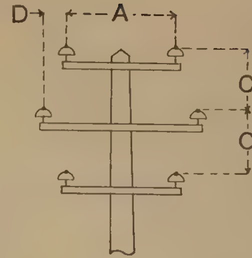
Average A. C. S. R. Conductor Spacing and unloaded sags, suitable for short spans on Pin Type Insulators in regions where the maximum loading is assumed to be, or approximates:

One-half inch (12.7 mm.) radial thickness of ice, with a wind pressure of 8 lb. per square foot (39 kg. per square meter) of projected ice-covered area, occurring simultaneously at 0°F. (−18°C.)







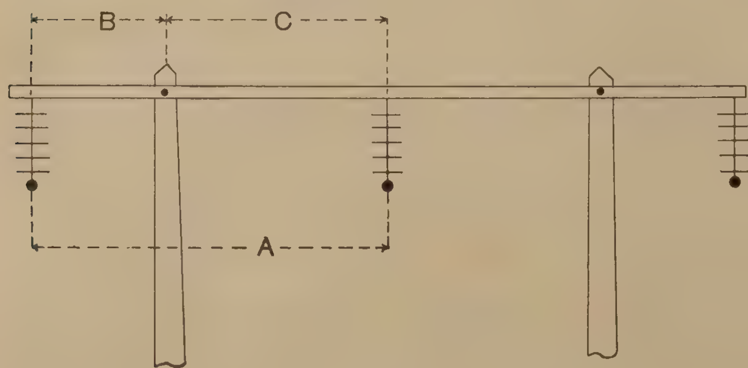


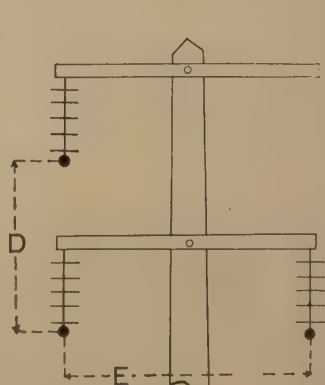
Voltage	Size A. C. S. R. (A. W. G.)	A inches			B inches			C inches			D inches			Vertical sag (inches), temperature Fahrenheit											
														200′ span				250′ span				300′ span			
		200′ span	250′ span	300′ span	200′ span	250′ span	300′ span	200′ span	250′ span	300′ span	200′ span	250′ span	300′ span	−20 deg.	32 deg.	60 deg.	120 deg.	−20 deg.	32 deg.	60 deg.	120 deg.	−20 deg.	32 deg	60 deg.	120 deg
11,000	No. 4	30	36	..	30	36	..	..	..	..	..	..	..	20	26	29	37	42	48	51	61	71	78	81	94
11,000	No. 2	30	36	42	30	36	42	..	..	..	..	..	..	8	15	20	27	16	25	31	40	31	42	48	58
11,000	1/0	24	30	36	24	30	36	..	..	..	..	..	..	7	12	16	26	10	17	22	34	16	28	35	47
11,000	4/0	24	30	30	24	30	36	..	..	..	..	..	..	6	10	14	24	9	16	21	33	14	24	30	43
22,000	No. 4	48	54	..	48	54	..	36	42	..	12	12	..	20	26	29	37	42	48	51	61	71	78	81	94
22,000	No. 2	42	48	54	42	48	54	30	36	42	12	12	12	8	15	20	27	16	25	31	40	31	42	48	58
22,000	1/0	36	42	48	36	42	48	24	30	36	12	12	12	7	12	16	26	10	17	22	34	16	28	35	47
22,000	4/0	36	42	42	36	42	42	24	30	30	12	12	12	6	10	14	24	9	16	21	33	14	24	30	43
33,000	No. 4	54	60	..	54	60	..	42	48	..	18	18	..	20	26	29	37	42	48	51	61	71	78	81	94
33,000	No. 2	48	54	60	48	54	60	36	42	48	18	18	18	8	15	20	27	16	25	31	40	31	42	48	58
33,000	1/0	42	48	54	42	48	54	30	36	42	18	18	18	7	12	16	26	10	17	22	34	16	28	35	47
33,000	4/0	42	48	48	42	48	54	30	36	42	18	18	18	6	10	14	24	9	16	21	33	14	24	30	43
44,000	No. 4	66	72	..	66	72	..	48	60	..	24	24	..	20	26	29	37	42	48	51	61	71	78	81	94
44,000	No. 2	60	66	72	60	66	72	42	54	60	24	24	24	8	15	20	27	16	25	31	40	31	42	48	58
44,000	1/0	60	60	66	60	60	66	36	42	48	24	24	24	7	12	16	26	10	17	22	34	16	28	35	47
44,000	4/0	60	60	60	60	60	60	36	42	48	24	24	24	6	10	14	24	9	16	21	33	14	24	30	43

Spacing with Suspension Insulators, Wood Poles

Average A. C. S. R. conductor spacing on wood poles with suspension insulators in regions where the maximum loading is assumed to be, or approximates: ½ in. (12.7 mm.) radial thickness of ice, with a wind pressure of 8 lb. per square foot (39 kg. per square meter) of projected ice-covered area, occurring simultaneously at 0°F. (−18°C.).

Voltage	A feet	B feet	C feet	D feet	E feet
33,000	6.5	3	4	6	7
66,000	9.5	4	5.5	7	8
110,000	13.5	6	7.5	10	10

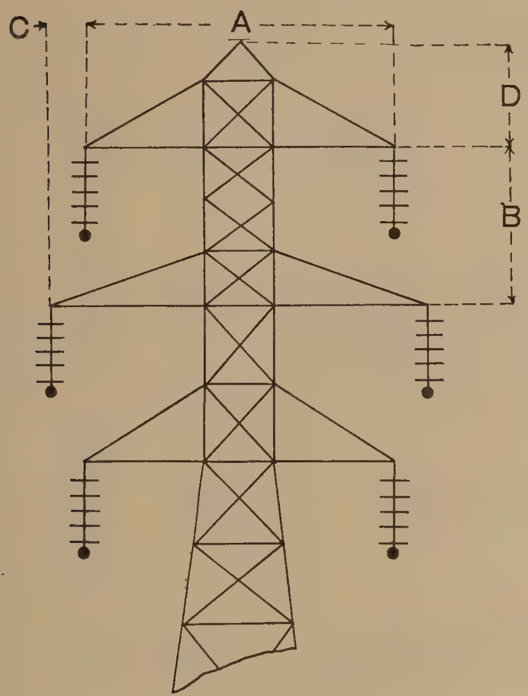


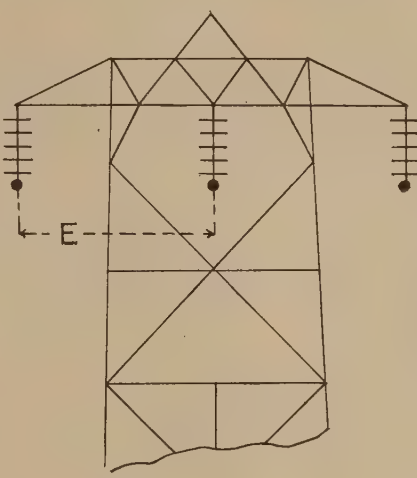


Spacing with Suspension Insulators, Steel Towers

Average A. C. S. R. conductor spacing on steel towers with suspension insulators in regions where the maximum loading is assumed to be, or approximates: ½ in. (12.7 mm.) radial thickness of ice, with a wind pressure of 8 lb. per square foot (39 kg. per square meter) of projected ice-covered area, occurring simultaneously at 0°F. (−18°C.).

Voltage	A feet	B feet	C feet	D feet	E feet
33,000	10	7	2	4	9
66,000	14	8	2	4	11
110,000	18	10	3	5	14
150,000	23	13	4	7	17





TRANSPOSITIONS

Transpositions in transmission lines are installed for two principal purposes: (*a*) To obtain symmetry in voltage, current and impedance of the transmission circuit itself; and (*b*) to minimize the possible inductive effects on neighboring circuits. Very long circuits in close proximity may induce relatively large voltages in each other. In case the circuit adjacent to a transmission line is a power circuit, the effects are usually of minor importance, but in the case of a telephone circuit, the induced current may be large in comparison with the "operating current" of the telephone circuit, and lead to noise interference. Transpositions may be installed in the telephone circuit or in the power circuit, or in both circuits for this purpose. If transpositions are installed in both circuits, they should be "co-ordinated" so that the combination is most effective. If the transmission lines are not transposed, there is a tendency to produce unbalanced voltages between the transmission conductors and ground; or if the transmission system is grounded, to cause currents to flow through the ground connections. If this unbalance in voltage to ground or the residual current is large, noise may be experienced in adjacent circuits. From the power standpoint, the principal disadvantage from the omission of transposition is the unbalance in line currents and line voltages. It is now general practice to install transpositions in the more important transmission circuits. It may be well to consult the engineers of the local telephone companies when important new power transmission lines are being planned.

DATA UPON HIGH VOLTAGE TRANSMISSION LINES

Ref. No.	Company and Location	Terminals of Transmission Line	Voltage	Cycles	Length of Line (Miles)	Year Built	Conductors: Circuits per Tower	Size-Material	Normal Arrangement	Normal Spacing (Feet-Inches): Horizontal	Normal Spacing (Feet-Inches): Vertical	To Ground (Feet)	To Highway (Feet)	To Tracks (Feet)	To Telephone (Feet)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1	Southern California Edison Co., Los Angeles, Cal., U. S. A.	Big Creek–Eagle Rock	220,000	50	240	1923	1	605,000 C.M. A.C.S.R.	Horizontal	17'3"		25'–30'	30	34	12
2	Southern California Edison Co., Los Angeles, Cal., U. S. A.	Eagle Rock–Laguna Bell	220,000	50	26	1923	1	666,600 C.M. A.C.S.R.	Horizontal	22'3"		25'–30'	30	34	12
3	Pacific Gas & Electric Co., San Francisco, Cal., U. S. A.	Pit River–Vaca–Dixon	220,000	60	202	1922	1 and 2	518,000 C.M. A.C.S.R.	Horizontal and vertical	19'0"	15'0"	30'	30	34	
4	City of Seattle, Seattle, Washington	Seattle–Skagit River	165,000	60	100	1923	1	477,000 C.M. A.C.S.R.	Horizontal	15'0"		30	34	34	25
5	Great Western Pr. Co., San Francisco, Cal., U. S. A.		165,000		200		1	336,000 C.M. A.C.S.R.	Horizontal–unequal triangle	15'–17'	14'				
6	Daido Electric Pr. Co., Osaka, Japan	Kiso River–Osaka	154,000	60	155	1923	2	500,000 C.M. A.C.S.R.	Horizontal	21'9"	13'0"				
7	Keihin Electric Pr. Co., Tokoyo, Japan	Mimnegana–Yokohama	154,000	50	125	1922	2	409,000 C.M. A.C.S.R.	Vertical with offset	25'0"	13'6"				
8	City of San Francisco, San Francisco, Cal.	Hetch–Hetchy	154,000	60	98		2	397,500 C.M. A.C.S.R.		24'–28'	15'0"	62			
9	Knoxville Pr. Co., Knoxville, Tenn., U. S. A.		150,000		25		1	500,000 C.M. A.C.S.R.	Horizontal	17'6"					
10	Consumers Pr. Co., Jackson, Mich., U. S. A.		140,000		26		2	0000 A.C.S.R.	Vertical	16'0"	12'0"				
11	Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wisc., U. S. A.	Milwaukee–Racine	132,000	60	22	1924	2	0000 Copper	Vertical with offset	23'0"	12'0"	25	30	36	12
12	Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wisc., U. S. A.	Milwaukee–Plymouth	132,000	60	69	1923	2 ult.	000 A.C.S.R.	Vertical with offset	23'0"	12'0"	20	30	36	12
13	Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wisc., U. S. A.	Racine–Kenosha	132,000	60	8	1925	2	0000 Copper	Vertical with offset	27'0"	13'0"	27	30	36	12
14	Wisconsin Gas & Elect. Co., Racine, Wisc., U. S. A.	Plymouth–Green Bay	132,000	60	75	1925	2 ult.	0000 A.C.S.R.	Vertical with offset	27'0"	13'0"	27	30	36	12
15	Wisconsin Gas & Elect. Co., Racine, Wisc., U. S. A.	Amberg–Twin Falls	132,000	60	28	1925	2 ult.	0000 A.S.C.R.	Vertical with offset	27'0"	13'0"	27	30	36	12
16	Milwaukee Elec. Ry. & Lt. Co., Milwaukee, Wisc., U. S. A.	Milwaukee–Whitewater	132,000	60	50	1924	2 ult.	000 A.C.S.R.	Vertical with offset	23'0"	12'0"	25	30	36	12
17	Ohio Public Service Co., Cleveland, Ohio, U. S. A.	Ashland–Lorain	132,000	60	44	1924	1	336,400 C.M. A.C.S.R.	Vertical with offset	22'6"	12'0"	25	35	40	
18	Kansas Gas & Electric Co., Kansas, U. S. A.	Neosho–Median	132,000	60	106	1922	2	266,800 C.M. A.C.S.R.	Vertical with offset	21'0"	13'0"	27	27	33.3	9.3
19	Idaho Power Company, Idaho, U. S. A.	Thousand Springs–Caldwell	132,000*	60	114.2	1921	1	0000 A.C.S.R.	Horizontal	14'0"		25	30	34.5	
20	Texas Power & Light Co., Texas, U. S. A.	Hillsboro–Leon	132,000	60	100	1924	1	0000 A.C.S.R.	Horizontal	14'6"		26	25	35	9
21	Utah Power & Light Co., Utah, U. S. A.	Grace–Terminal	132,000	60	133.3	1914	2	250,000 C.M. Copper	Vertical	21'0"	13'0"	25	30	30	10
22	Utah Power & Light Co., Utah, U. S. A.	Olmstead–Helper	132,000†	60	71	1916	1	0000 Copper steel	Horizontal	13'0"		25	30	30	10
23	Utah Power & Light Co., Utah, U. S. A.	Grace–Terminal	130,000	60	134.4	1917	1	250,000 C.M. Copper	Horizontal	13'0"		25	30	30	10
24	State of Victoria Electricity Com., Victoria, Australia	Morwell–Melbourne	130,000	50	112	1923	2	336,400 C.M. A.C.S.R.	Vertical	19'8"	11'0"				
25	S. A. Hydroelectrica Iberica, Spain	Ebro River	130,000	50	187		2	323,000 C.M. A.C.S.R.	Vertical with offset	14'6"	9'2"				
26	Forces Mortices Bernoises, Switzerland		130,000	50	12		2	336,400 C.M. A.C.S.R.	Vertical with offset	23'7"	11'7"				
27	Metropolitan Edison Co., Reading, Pa., U. S. A.	Middletown–Reading	114,000	60	49	1924	1	0000 A.C.S.R.	Horizontal	12'9"		27	30	35	14–15
28	Metropolitan Edison Co., Reading, Pa., U. S. A.	Reading–Easton	114,000	60	48	1923	2	336,400 C.M. A.C.S.R.	Vertical with offset	18'0"	10'0"	27	30	35	14–15
29	Minnesota Power & Light Co., Minnesota, U. S. A.	Blanchard–Nashwauk	110,000	60	126	1924	1	0000 Copper	Horizontal	11'0"		25	24.5	32.5	8.5
30	Pacific Power & Light Co., Portland, Oregon, U. S. A.	Lind–Pasco	110,000‡	60	66	1917	1	0 Copper	Unequal triangle	10'0"	9'0"	32 Ave.	23 Min.	34 Min.	8
31	Cia Cubana de Electricidad, Inc., Cuba	Cienfuegos–Santa Clara	110,000	60	40	1924	1	000 Copper	Horizontal	12'0"		27	27		8.5
32	Alabama Power Co., Birmingham, Ala., U. S. A.	Lock 18–Cherokee Bluffs	110,000	60	20	1923	1	397,500 C.M. Copper	Horizontal	14'0"			30	30	18
33	San Joaquin Lt. & Pr. Com., Los Angeles, Cal., U. S. A.	Kerchoff–Merced	110,000	60	64	1920	1	266,800 C.M. A.C.S.R.	Unequal triangle	10'0"	10'0"				
34	New England Pr. Co., Worcester, Mass., U. S. A.	Davis Bridge–Millbury	110,000	60	74	1924	2	0000 Copper	Horizontal	12'6"		25	30	38	
35	Penn Public Service Corp., Johnstown, Pa., U. S. A.	Glory–Piney	110,000	60	48	1924	2	0000 A.C.S.R.				26	26	30–40	
36	Adirondack Pr. & Lt. Co., Schenectady, N. Y., U. S. A.	Sherman–Rotterdam	110,000	60	38	1922	2	0000 Copper	Vertical with offset	21'0"	9'6"	22.5	25	34	9

* Operated at 66Kv.
† Operated and Insulated for 44Kv.
‡ Operated and Insulated for 66Kv

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

Ref. No.	SPANS: Normal Span (Feet)	SPANS: Maximum Span (Feet)	SPANS: Normal Sag (Feet)	SPANS: Normal Tension (Pounds)	TOWERS: Material of Towers	TOWERS: Material of Cross Arms	TOWERS: Material of Pins	TOWERS: Height of Lowest Conductor (Feet)	INSULATORS: Straight Runs Number–Type	INSULATORS: Strain Number–Type	GROUND WIRE: Material	GROUND WIRE: Points Grounded
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
1	660	2870	9 at 80°F.	8000 Max.	Steel	Steel		37	12–10″ Susp.	2 × 13–10″ Susp.	½″ steel	Every tower
2	1250	2731	19 at 80°F.	12000 Max.	Steel	Steel		52.5	13–10″ Susp.	2 × 15–10″ Susp.	½″ steel	Every tower
3	600–800	1802	16–22	3300–6000	Steel-wood H frame	Wood-Steel		45	2–13″–11–10″ Susp.	2–13″–10–10″ Susp.		
4	600	1475	13	3500	2 pole H-frame	Wood	None	50	10–Susp.	12 or 14 Susp.	None	Every tower
5	750	1850			Steel				–Susp.	–Susp.		
6	1200	3200			Steel				–Susp.	–Susp.		
7	750	1450			Steel				–Susp.	–Susp.		
8	1000				Steel							
9	1700	5010			Steel				–Susp.			
10	500	600			Steel				–Susp.			
11	650	650	20.3	1678	Steel	Steel		45.5	10–Susp.	12–Susp.	None	
12	650	665	18	687	Steel	Steel		45.5	10–Susp.	12–Susp.	None	
13	600	650	15.3	1920	Steel	Steel		45.5	10–Susp.	12–Susp.	None	
14	600	650	12.6	1050	Steel	Steel		45.5	10–Susp.	12–Susp.	None	
15	1000	1000	27.5	1840	Steel	Steel		55.5	10–Susp.	12–Susp.	None	
16	650	1065	18	687	Steel	Steel		45.5	10–Susp.	12–Susp.	None	
17	880	1000	14	3500	Steel	Steel		51	10–Susp.	10–Susp.	None	
18	850	1350	14.5	2160	Steel	Steel	None	44.7	9–Susp.	11–Susp. 2 Str.	None	
19	550		5.5	2300	Wood	Wood	None	42	9–Susp.	11–Susp. 2 Str.	None	
20	550	1500	9.5	1400	Wood	Wood	None	38	9–Susp.	11–Susp. 2 Str.	None	
21	652		14	3000	Steel	Steel	None	40	10–Susp.	12–Susp. 2 Str.	2–⅜ S.M.	Every tower
22	500		10	2000	Wood	Wood	None	40	5–Susp.	7–Susp. 2 Str.	1–5/16 S.M.	Every tower
23	500		10	2500	Wood	Wood	None	40	10–Susp.	12–Susp. 2 Str.	1–5/16 S.M.	Every tower
24	1056	2300			Steel				–Susp.	–Susp.		
25	656	1860			Steel				–Susp.	–Susp.		
26	660	2200			Steel				–Susp.	–Susp.		
27	575	1595	8	5000	Wood H frame	Steel		38	7–Susp.	9–Susp.	None	Every pole
28	770	2225	15	8000	Steel	Steel		38	9–Susp.	2 × 9–Susp.	None	Every pole
29	550	1067	15.2	1850	Wood	Wood	None	43	7–Susp.	9–Susp. 2 Str.	None	
30	250	500	2.5	1050	Wood	Wood	None	35	5–Susp.	7–Susp.	1–⅜ S.M.	
31	650		14	2200	Steel	Steel	None	41	7–Susp.	9–Susp.	None	
32	690	2180	10		Wood H frames			40	7–Susp.	8–Susp.		
33	597	850			Wood	Steel			7–Susp.	8–Susp.		
34	700		25	1600	Steel	Steel		46	8–Susp.	9–Susp.	7/16″ cru. st.	
35	1257	2290	48	1200	Steel	Steel		68	9–Susp.	10–Susp.	None	
36	660	1100	18	4000	Steel	Steel		45	8–Susp.	9–Susp.	⅜″ copper clad	2 pipes per tower

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

Ref. No.	COMPANY AND LOCATION	Terminals of Transmission Line	Voltage	Cycles	Length of Line (Miles)	Year Built	CONDUCTORS: Circuits per Tower	Size-Material	Normal Arrangement	Normal Spacing (Feet-Inches): Horizontal	Normal Spacing (Feet-Inches): Vertical	To Ground (Feet)	To Highway (Feet)	To Tracks (Feet)	To Telephone (Feet)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
37	Virginia Ry. & Pr. Co., Richmond, Va., U. S. A.	Petersburg–Richmond	110,000	60	25	1918	1	0 Copper	Unequal triangle		8′0″	25	28	28	
38	Virginia Western Pr. Co., Clifton Forge, Va., U. S. A.	Staunton–Charlottesville	110,000	60		1924		0000 A.C.S.R.				20	25	40	50
39	Georgia Ry. & Pr. Co., Atlanta, Ga., U. S. A.	Boulevard–Tallulah	110,000	60	87	1913	1	0000 Copper	Vertical	16′0″	9′0″	30	30	35–45	12–15
40	Compania Chileno De Elect., Chili, South America		110,000		66		2	000 A.C.S.R.	Vertical with offset	17′6″	9′6″				
41	Shawinigan Water & Pr. Co., Shawinigan Falls, Canada	Shawinigan Falls–Montreal	110,000	62½	86	1921	2	266,800 C.M. A.C.S.R.	Vertical with offset	20′0″	10′0″	22–27	22–27	35	18
42	Cia de Luz, Fuerza y Tranvias de Pueblo, Mexico	Tuxbango–Pueblo	110,000	60	80		1	240,000 C.M. Alum							
43	Cedars Rapids Transmission Co., Potsdam, N. Y., U. S. A.	Cedars–Massena	110,000	60	52		2	500,000 C.M. A.C.S.R.	Vertical with offset	11′6″	10′0″				
44	Niagara Lockport and Ont. Pr. Co., Lockport, N. Y., U. S. A.		110,000		38		2	336,400 C.M. A.C.S.R.	Vertical with offset	14′3″	8′0″				
45	Utica Gas & Electric Co., Utica, N. Y., U. S. A.	Utica–Boonville	110,000	60	30	1923	2	0000 Copper	Vertical with offset	14′0″	10′0″	25	25	32	
46	Hydro-Elec. Pr. Com. of Ontario, Ontario, Canada	Queenstown–Nelson Jct.	110,000	25	46.15	1923	2	605,000 C.M. A.C.S.R.	Vertical with offset	19′6″	11′0″	24	24	35	
47	Hydro-Elec. Pr. Com. of Ontario, Ontario, Canada	Dundas–Stratford	110,000	25	69.22	1910	2	336,400 C.M. A.C.S.R.	Unequal triangle	8′0″	10′1.5″	24	24	35	
48	Hydro-Elec. Pr. Com. of Ontario, Ontario, Canada	St. Thomas–Windsor	110,000	25	102.81	1914	2	167,800 C.M. Copper	Vertical with offset	16′8″	8′6″	24	24	35	
49	Carolina Power & Light Co., Raleigh, North Carolina, U. S. A.	Badin–Sanford	110,000	60	62	1922	2	397,500 C.M. A.C.S.R.	Vertical with offset	23′0″	10′0″	25	27	30	
50	Yadkin River Power Co., Raleigh, North Carolina, U. S. A.	Blewett–Durham	110,000	60	87	1911	2	0 Copper	Vertical with offset	23′0″	9′0″	27	27	30	
51	Pacific Gas & Elect. Co., San Francisco, Cal., U. S. A.	Typical 110 Kv. lines	110,000	60	48	1923	2	250,000 C.M.	Vertical		10′0″	30	30	34	
52	Georgia Railway & Power Co., Atlanta, Georgia, U. S. A.	Marietta–Lindale	110,000	60	52	1924	2	00 Copper	Vertical	15′0″	9′0″	30	30	35–45	12–15
53	Virginia Railway & Power Co., Richmond, Va., U. S. A.	Suffold–Roanoke Rapids	110,000	60	65	1925	1	00 Copper	Vertical with offset	20′0″	10′0″	25	30	28	
54	Penn Central Lt. & Pr. Co., Philadelphia, Pa., U. S. A.		110,000	60	78	1923	2	250,000 C.M. Copper	Vertical	21′0″	10′0″				
55	Pacific Power & Light Co., Portland, Oregon, U. S. A.	Hanford–Taunton	110,000	60	15	1925	1	0 Copper	Horizontal	11′0″		30	30	34	10
56	Southern Power Co., Charlotte, North Carolina, U. S. A.	Standard 100,000 volt lines	100,000		60		2	0000 Alum	Vertical with offset	18′0″	10′0″				
57	Public Service Co. of Colorado, Denver, Col., U. S. A.	Denver–Shoshone	90,000	60	153	1907	1	0 Copper–Hemp core	Horizontal	11′0″		30	30	35	
58	Public Service Co. of Colorado, Denver, Col., U. S. A.	Valmont–Denver	90,000	60	28	1924	2	336,000 C.M. A.C.S.R.	Vertical with offset		12				
59	Appalachian Pr. Co., Bluefield, W. Va., U. S. A.	Byllesby–Sollville	88,000	60	94	1922	1	0 Alum				20		35	10
60	Lake Superior Dist. Pr. Co., Ashland, Wisc., U. S. A.	Ironwood–Big Falls	88,000	60	88	1922	1	132,000 C.M. Alum				40	40	45	12
61	Kentucky and West Virginia Pr. Co., Hazard, Ky., U. S. A.		88,000		25		1	0000 A.C.S.R.	Horizontal	9′0″					
62	St. Lawrence County Utilities Corp., Potsdam, N. Y., U. S. A.	Massena–Ogdensburg	88,000	60	75	1913	2	000 A.C.S.R.	Vertical with offset	18′0″	9′9″	28	30	30	8
63	Southern Sierras Power Co., Riverside, Cal., U. S. A.	El Centro–Henshaw Dam	88,000	60	86	1924	1	00 Copper	Right angle	9′9″	8′0″	30	30	34	
64	Southern Sierras Power Co., Riverside, Cal., U. S. A.	Leevining No. 1–Control Station	88,000	60	76	1924	1	0000 A.C.S.R.	Horizontal	12′8″		32	32		
65	Carolina Power & Light Co., Raleigh, N. C., U. S. A.	Method–Buckhorn	66,000	60	23	1909	1	#2 Copper–Hemp core	Horizontal	10′0″		25	25	30	
66	Pennsylvania Power & Light Co., Allentown, Pa., U. S. A.	Hauto–Frackville	66,000	60	21.8	1921	1	0000 A.C.S.R.	Unequal triangle	15′0″	8′0″	27	27		
67	Pennsylvania Power & Light Co., Allentown, Pa., U. S. A.	Harwood–Wilkesbarre	66,000	60	20.1	1922	2	0000 Copper	Vertical with offset	18′0″	8′0″	27	27	38.5	12.7
68	Pennsylvania Power & Light Co., Allentown, Pa., U. S. A.	Williamsport–Lock Haven	66,000	60	27	1924	1	00 Copper	Triangle	8′6″	6′0″	27	27	31.7	9.4
69	Metropolitan Edison Co., Reading, Pa., U. S. A.	Middletown–York	66,000	60	17.7	1924	2	0000 A.C.S.R.	Vertical with offset	18′0″	10′0″	25	30	32	8–10
70	Pacific Power & Light Co., Portland, Oregon, U. S. A.	Pendleton–Pasco	66,000	60	63	1923	1	0 Copper	Triangle	8′0″	6′0″	32 Ave.	23 Min.	34 Min.	8
71	New England Pr. Co., Worcester, Mass., U. S. A.	Lincoln–Seekonk	66,000	60	14	1923	2	00 Copper	Horizontal	10′0″		25	30	34	
72	Connecticut Power Co., Hartford, Conn., U. S. A.	Falls Village–Hartford	66,000	60	11	1914	2	#2 Copper				37			

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

	SPANS				TOWERS				INSULATORS		GROUND WIRE	
									Straight Runs	Strain		
Ref. No.	Normal Span (Feet)	Maximum Span (Feet)	Normal Sag (Feet)	Normal Tension (Pounds)	Material of Towers	Material of Cross Arms	Material of Pins	Height of Lowest Conductor (Feet)	Number–Type	Number–Type	Material	Points Grounded
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
37	660	800	16	1600	Steel	Steel		38	9–Susp.	9–Susp.	⅜″ steel	Every tower
38	800	1300			Steel	Steel		50	7–Susp.	8–Susp. 2 Str.	Copper clad	
39	500	1200			Steel	Steel		41	7–Susp.	9–Susp.	2–7/16″ steel	Every tower
40	984	2000			Steel				–Susp.	–Susp.		
41	530	1290	15	800	Steel	Steel		42.5	–Susp.	–Susp.	None	
42	770	1200			Steel				–Susp.	–Susp.		
43	660	1525			Steel	Steel			–Susp.	–Susp.	Steel	Every tower
44	550	1280			Steel				–Susp.	–Susp.		
45	545	852	16	1800	Steel	Steel	None	39	8–Susp.	10–Strain	7/16″ S.M. cable	Every tower
46	880				Steel	Steel		46	–Susp.	–Susp.		
47	550				Steel	Steel		48	–Susp.	–Susp.		
48	660				Steel	Steel		44	–Susp.	–Susp.		
49	750	2181	12	3000	Steel	Steel	None	40	7–Susp.	9–Susp. 2 and 3 Str.	7/16″ high str. galv.	Every tower
50	680	1455	14.5	1280	Steel	Steel	None	45	7–Susp.	8–Susp.	⅜ S.M.	Every tower
51	800	1888	21.5	2800	Steel	Steel		54	7–12″ Susp.	8–12″ Susp.		
52	500				Steel	Steel		44	7–10″ Susp.	9–10″ Susp.	7/16″ steel	Every tower
53	660	900	15	1465	Steel	Steel		38	9–Susp.	9–Susp.	⅜″ steel	Every tower
54	500	2885			Steel	Steel			–Susp.	–Susp.		
55	550	1200	13.25	925	Wood H frames	Wood	Steel	43	6–Susp.	7–Susp.	None	
56	550				Steel				–Susp.	–Susp.		
57	720	1980	18	1250	Steel	Steel		40	5–Susp.	6–Susp.	None	
58					Steel	Steel		40	7–Susp.	7–Susp. H. Duty		
59	600	1800		1100	Wood	Wood		34	5–Susp.	6–Susp.	Gal. steel	Every 5th pole
60	600	1000	15	1400	Steel	Steel		40	6–Susp.	7–Susp.	Str. steel	Every 5th pole
61	400	2280			Wood H frames				–Susp.	–Susp.		
62	550	1000			Steel	Steel		44	–Susp.	–Susp.	Gal. steel	Every tower
63	406	1048	5.8	2610 Max.	Wood	Steel	C.I. and steel		5–Susp.	6–Susp.		
64	528	857	9.6	1050	Wood H frames	Wood		42	7–Susp.	8–Susp.		
65	700	1250	17		Steel	Steel	None	40	4–Susp.	5–Susp.	⅜″ S.M.	Every tower
66	700	1844	13	1385	Steel	Steel	None	47	4–Susp.	6–Susp. 2 Str.	⅜″ H.S.S.	Every tower
67	600	1403			Steel	Steel	None	50	4–Susp.	6–Susp. 2 Str.	None	
68	200	1310	2.8	720	Wood	Wood	Steel		1–Pin	6–Susp.	None	
69	675	2136	11.75	5000	Steel	Steel		38	5–Susp.	7–Susp.	None	Every pole
70	250	500	2.5	1050	Wood	Wood	Steel	34	1–Pin	5–Susp.	None	
71	325		9	600	Wood H frames	Steel		30	5–Susp.	6–Susp.	None	Each crossarm
72	450	1100	14		Steel	Steel		37	5–Susp.	6–Susp.	Steel strand	

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

Ref. No.	COMPANY AND LOCATION	Terminals of Transmission Line	Voltage	Cycles	Length of Line (Miles)	Year Built	CONDUCTORS: Circuits per Tower	Size Material	Normal Arrangement	Normal Spacing (Feet-Inches): Horizontal	Vertical	To Ground (Feet)	To Highway (Feet)	To Tracks (Feet)	To Telephone (Feet)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
73	East Penn Elect. Co., Pottsville, Pa., U. S. A.	Pine Grove–Fishbach	66,000	60	7		2	0000 Copper				32.5	42.5	39	20
74	Duquesne Lt. Co., Pittsburgh, Pa., U. S. A.	Woodville–Dravosburg	66,000	60	86	1921	2	0000 Alum				25	31	31	
75	United Hudson Elec. Ry. Co., Poughkeepsie, N. Y., U. S. A.	Hudson–Poughkeepsie	66,000	60	23	1920	2	0 Copper				23	30	30	5
76	Adirondack Pr. & Lt. Co., Schenectady, N. Y., U. S. A.	Inghams Mills–Tribes Hill	66,000	60	28	1908	2	#2 Copper	Vertical	10'6"	6'0"	25	25	31	8
77	West Penn. Co., Pittsburgh, Pennsylvania, U. S. A.	Howesville–Oakland	66,000	60	20	1923	1	0000 Copper				25	30	40	10
78	Peninsular Pr. Co., Madison, Wisc., U. S. A.		66,000	60		1921	2	#2 Copper				20	25	30	8
79	Northern States Pr. Co., Chicago, Illinois, U. S. A.	Alma Center–La Crosse	66,000	60	73	1922	1	0 Alum							
80	Wisconsin Public Service Corp., Milwaukee, Wisc., U. S. A.	Green Bay–Sturgeon Bay	66,000	60	54	1920	1	#2 A.C.S.R.	Unequal triangle	6'0"	6'0"	31	31	31	
81	Niagara, Lockport & Ontario Pr. Co., Lockport, N. Y., U. S. A.		66,000		100		2	0000 A.C.S.R.	Vertical with offset	15'6"	8'0"				
82	East Kootenay Lt. & Pr. Co., Fernie, B. C., Canada		66,000		106		1	#2 and 3 A.C.S.R.	Equilateral triangle	6'0"					
83	New Brunswick Elec. Pr. Com., St. John, N. B., Canada		66,000		90		1	00 A.C.S.R.	Horizontal	7'6"					
84	San Joaquin Lt. & Pr. Co., Los Angeles, Cal., U. S. A.		66,000		64		1	266,800 C.M.000 Alum	Unequal triangle	7'6"	6'4"				
85	Wisconsin-Minn. Lt. & Pr. Co., Chicago, Ill., U. S. A.		66,000		110		1	000 A.C.S.R.	Unequal triangle	7'0"	6'0"				
86	Northwestern Elect. Co., Portland, Oregon, U. S. A.		66,000		70		1	266,800 C.M. A.C.S.R.	Unequal triangle	7'0"	7'0"				
87	City of Winnipeg, Winnipeg, Man., Canada	Pointe du Bois–Winnipeg	66,000	60	77	1919	2	278,600 C.M. Alum	Vertical with offset	8'6"	7'0"				
88	Penninsular Pr. Co., Milwaukee, Wisc., U. S. A.	Twin Falls–Iron River	66,000	60	38		2	0 A.C.S.R.	Vertical with offset	10'0"	8'0"				
89	Milwaukee Electric Ry. & Lt. Co., Milwaukee, Wisc., U. S. A.	Watertown–West Allis	66,000	25	42	1915	2	0 Copper	Vertical	12'0"	6'0"		30	36	12
90	Union Gas & Electric Co., Cincinnati, Ohio, U. S. A.	Trenton–Elmwood No. 1	66,000	60	28.3	1923	1	477,000 C.M. A.C.S.R.	Unequal triangle	8'0"	7'0"	22	24	34.5	10
91	Union Gas & Electric Co., Cincinnati, Ohio, U. S. A.	Miami–Fort Hartwell Cts. H-2	66,000	60	20	1925	2	400,000 C.M. Copper	Vertical with offset	19'0"	12'0"	26	28	36	17
92	Georgia Railway & Power Co., Atlanta, Ga., U. S. A.	Lindale–State Line	66,000	60	62	1911	1	0 Copper	Unequal triangle	7'0"	7'0"				
93	Wisconsin River Power Co., Madison, Wisc., U. S. A.	Madison–Janesville	66,000	60	37	1919	2	0 A.C.S.R.	Vertical with offset	11'0"	6'0"				
94	Wisconsin River Power Co., Madison, Wisc., U. S. A.	Prairie du Sac–Portage	66,000	25	23	1915	2	0 Copper	Vertical with offset	13'0"	6'0"				
95	Wisconsin River Power Co., Madison, Wisc., U. S. A.	Prairie du Sac–Madison	66,000	60	30	1915	2	00 A.C.S.R.	Vertical with offset	10'6"	6'6"				
96	Southern Wisconsin Pr. Co., Madison, Wisc., U. S. A.	Kilbourn–Watertown	66,000	25	69	1908	2	0 Copper	Vertical	11'0"	6'0"				
97	Wisconsin Pr. & Lt. Co., Madison, Wisc., U. S. A.	Dane–Fond du Lac	66,000	60	84	1922	1	00 A.C.S.R.	Unequal triangle	8'0"	6'0"				
98	Wisconsin Pr. & Lt. Co., Madison, Wisc., U. S. A.	Fond du Lac–Sheboygan	66,000	60	42	1921	1	#2 Copper	Unequal triangle	7'0"	6'0"				
99	Western States Gas & Elec. Co., Stockton, Cal., U. S. A.	El Dorado–Stockton	60,000	60	200	1923	1	00 Copper	Horizontal	4'7"		30	30	35	6
100	Kansas Gas & Electric Co., Kansas, U. S. A.	Cherryvale–Buffville	60,000	60	16.7	1923	1	00 Copper	Triangle	8'0"	5'0"	28.5	28.5	32	
101	Texas Power & Light Co., Texas, U. S. A.	Waco–Fort Worth	60,000	60	51	1913	2	0 Copper	Vertical	11'0"	8'0"	25	25	35	10
102	Utah Power & Light Co., Utah, U. S. A.	Springvale–Cameron	44,000	60	55	1923	1	00 Copper	Triangle	6'0"					
103	Minnesota Power & Light Co., Minnesota, U. S. A.	Winton Sta.–Tower	44,000	60	25.8	1924	1	#2 Copper	Triangle	5'0"		22	22	30	6
104	Utica Gas & Electric Co., Utica, N. Y., U. S. A.	Utica–Trenton Falls	44,000	60	12.5	1917	1	0 Copper	Vertical with offset	7'0"	4'6"	30	30		
105	Public Service Co. of Colorado, Denver, Col., U. S. A.	Valmont–Fort Collins–Greeley	44,000	60	125	1909	1	# 1 Copper	Equilateral triangle	4'0"					
106	Vermont Hydro Elect. Corp., Rutland, Vt., U. S. A.	Cavendish–Mendon	44,000	60		1913	1	#4 Copper				20–25	30	35–40	5
107	Penn Central Lt. & Pr. Co., Altoona, Pa., U. S. A.	Standard Lines	44,000	60	307			Copper–Alum							
108	Virginia Western Pr. Co., Clifton Forge, Va., U. S. A.	Roncoverte–Hinton	44,000	60	25	1916	1	0 Alum	Equilateral triangle	4'4"		18	24	30	6

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

	SPANS				TOWERS				INSULATORS		GROUND WIRE	
									STRAIGHT RUNS	STRAIN		
Ref. No.	Normal Span (Feet)	Maximum Span (Feet)	Normal Sag (Feet)	Normal Tension (Pounds)	Material of Towers	Material of Cross Arms	Material of Pins	Height of Lowest Conductor (Feet)	Number–Type	Number–Type	Material	Points Grounded
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
73	560	940	21	3000	Steel	Steel		52	5–Susp.	6–Susp.	Steel	Every tower
74	647	1123	29.6		Steel	Steel		60 Ave.	6–Susp.	7–Susp.	3/8″ steel	Every tower
75	530	750			Steel	Steel		50	5–Susp.	6–Susp.	3/8″ steel	
76	600	933	17	400	Steel	Steel	Steel	43	1–Pin	7–Susp.	5/16″ steel	Every tower
77	460	1400		2100	Wood	Wood		25	4–5–Susp.	5–6–Susp.	None	
78	500	650	17		Steel	Steel	Steel	42	5–Susp.	6–Susp.		
79		600			Wood	Wood	Steel	27	1–Pin	6–Susp.	Steel	Sta. Every 5th pole
80	200	320	1.5	500	Wood	Steel	Steel	32.5	1–Pin	6–Susp.	Str. steel	316
81	500	1200			Steel				–Susp.	6–Susp.		
82	300	850			Wood H frames				–Pin			
83	480	710			Wood H frames				–Susp.			
84	300	400			Wood				–Pin–Susp.			
85	300	1210			Wood				–Pin			
86	300	1100			Wood				–Pin			
87	400	1100	7.8	665	Steel	Steel	Steel	33	1–Pin	5–Susp.	3/8″ steel	Every tower
88	540	900			Steel	Steel	Steel		–Susp.			
89	550	649	16.4	750	Steel	Steel		38.5	4–Susp.	5–Susp.	5/16″ C.C. steel	Every tower
90	300	1300	4.25	1375	Wood	Wood	None	32.5	4–Susp.	4–Susp.	5/8″ gal. steel	Every 3rd pole
91	1200	1665	43	5100	Steel	Steel	None	80.5	6–Susp.	7–Susp.	3/8″ gal. steel	Every tower
92					Wood				4–10″ Susp.	5–10″ Susp.	None	
93					Steel	Steel		35	5–Susp.	6–Susp.	None	
94					Steel			40	4–Susp.	5–Susp.	3/8″ steel	
95					Steel	Steel		35	5–Susp.	6–Susp.	3/8″ steel	
96	500				Steel			40			2–3/8″ steel	
97	290				Wood	Wood	Steel	35	5–Susp.	6–Susp.	None	
98					Wood				5–Susp.	6–Susp.	1/4″ steel	
99	265	1000	2		Steel–Wood	Steel–Wood	Steel	30	–Pin	5–Susp.	None	
100	275	400	3.7	1050	Wood	Wood	Steel	35.3	1–Pin	6–Susp.	None	
101	600	800	14	940	Steel	Steel	None	45	4–Susp.	7–Susp.	3/8″ S.M.	
102	250	283			Wood	Wood	Wood		–Pin	–Pin	None	
103	300	535	9.15	300	Wood	Wood	Steel	32.1	–Pin	4–Susp.	#6 galv. iron	Every pole
104	400	550	12	2200	Steel	Steel	Steel	36	1–Pin	4–Susp.	7/16″ S.M. cable	Every tower
105	130	200			Wood	Wood	Steel	30	1–Pin	3–Susp.	None	
106	135	150	1.5		Wood	Wood	Steel	18	1–Pin			
107	500	2380	8		Wood–Steel		Steel	38	1–Pin	–Susp.	Steel	Every tower
108	150	900			Wood–Steel	Steel	Steel	30–100	–Pin	3–4–Susp.	S.M. steel	4 per mile

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

Ref. No.	COMPANY AND LOCATION	TERMINALS OF TRANSMISSION LINE	Voltage	Cycles	Length of Line (Miles)	Year Built	CONDUCTORS Circuits per Tower	Size-Material	Normal Arrangement	Normal Spacing (Feet-Inches) Hori-zontal	Ver-tical	To Ground (Feet)	To High-way (Feet)	To Tracks (Feet)	To Tele-phone (Feet)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
109	Southern Pr. Co., Charlotte, N. C., U. S. A.	Standard 44,000 Volt Lines	44,000	60	577		1	00 Alum–Copper				22	25	30	10
110	Georgia-Alabama Pr. Co., Albany, Georgia, U. S. A.	Albany–Valdosta	44,000	60	86	1924	1	00 A.C.S.R.				17	20	31	4
111	Trinidad Elec. Tr. Ry. & Gas Co., Trinidad, Col., U. S. A.	Trinidad–Raton District	44,000	60	57	1914	1	#3 Copper	Equilateral triangle	5'0"		20–30	26	30	8
112	Cia Brazileira de Tramways Luz de Forca, Brazil, S. A.		44,000		93		2	#1 A.C.S.R.	Equilateral triangle	5'7"					
113	Kentucky and West Virginia Pr. Co., Hazard, Ky., U. S. A.		44,000		80		2	0 A.C.S.R.	Equilateral triangle	4'4"					
114	Texas Central Pr. Co., San Antonio, Texas, U. S. A.		44,000		60		2	#2 and 0 A.C.S.R.	Unequal triangle	4'6"	4'0"				
115	Montgomery Lt. & Water Pr. Co., Birmingham, Ala., U. S. A		44,000		28		1	000 A.C.S.R.	Unequal triangle	6'0"	6'0"				
116	Sanitary Dist. of Chicago, Chicago, Ill., U. S. A.		44,000		30		3	270,000 C.M. A.C.S.R.	Equilateral triangle	6'0"					
117	Beaver River Pr. Corp., N. Y., U. S. A.		44,000		14		2	00 A.C.S.R.	Equilateral triangle	4'6"					
118	Sloss-Sheffield Steel & Iron Co., Alabama, U. S. A.	Bessemer Mines	44,000		45	1922	1	0 A.C.S.R.	Unequal triangle	5'0"	5'0"	22	25	30	8
119	Cumberland Power Co., Tennessee, U. S. A.		44,000		17		2	#4 A.C.S.R.	Equilateral triangle	4'4"					
120	Cia Cubana de Electricidad, Inc., Cuba	Santa Clara–Caibarien	33,000	60	40	1924	1	000 Copper	Horizontal	4'0"		23–6	27		7
121	Southern Sierras Power Co., Riverside, Cal., U. S. A.	Standard 33 kv lines	33,000	60	469	1913–25	1	#2–#8 Copper	Horizontal	3'0"		30	30	34	
122	Wisconsin River Power Co., Madison, Wisc., U. S. A	Prairie du Sac–Dodgeville	33,000	60	19	1921	1	#1 Copper	Equliateral triangle	5'0"					
123	Wisconsin Pr. & Lt. Co., Madison, Wisc., U. S. A.	Janeseville–Monroe	33,000	60	52	1924	1	#4 Copper	Horizontal	3'0"					
124	Wisconsin Pr. & Lt. Co., Madison, Wisc., U. S. A.	Prairie du Sac–Wantoma etc.	33,000	60	216	1918	1	#4 Copper	Horizontal	3'0"					
125	Arkansas Lt. & Pr. Co., Pine Bluff, Ark., U. S. A.		33,000		42			0000 A.C.S.R.	Unequal triangle	10'0"	10'0"				
126	Arkansas Valley Ry. Lt. & Pr. Co., Pueblo, Col., U. S. A		33,000		66		1	#1 Alum	Unequal triangle	6'0"	6'0"				
127	Wabash Valley Elect. Co., Clinton, Indiana, U. S. A.	Terre Haute–Lafayette	33,000		40		1	00 A.C.S.R.	Unequal triangle	3'0"	3'0"				
128	Interstate Public Service Corp., Indianapolis, Ind., U. S. A.	Indianapolis–Bedford	33,000		63		1	00 A.C.S.R.	Unequal triangle	4'2"	4'0"				
129	New Jersey Power & Lt. Co., Dover, N. J., U. S. A.		33,000		50		1	00 A.C.S.R.	Unequal triangle	5'0"	5'0"				
130	Central Maine Pr. Co., Augusta, Maine, U. S. A.		33,000		48		2	266,800 C.M. A.C.S.R.	Equilateral triangle	5'0"					
131	Union Gas & Elec. Co., Cincinnati, Ohio, U. S. A.		33,000		30		1	0 A.C.S.R.	Unequal triangle	6'0"	4'0"				
132	Cedar Valley Elect. Co., Charles City, Iowa, U. S. A.		33,000		54		1	000 A.C.S.R.	Unequal triangle	4'6"	4'6"				
133	Kentucky Utilities Co., Louisville, Ky., U. S. A.	Louisville, Ky.–Pocket, W. Va.	33,000		66		1	00 A.C.S.R.	Triangle	4'6"	4'6"				
134	Kentucky Utilities Co., Louisville, Ky., U. S. A.		33,000		10		1	0 A.C.S.R.	Triangle	4'6"	4'6"				
135	Niagara Falls Power Co., Niagara Falls, N. Y., U. S. A		22,000		40		2	500,000 C.M. Alum.	Vertical with offset	5'0"	5'0"				
136	Indiana & Michigan Elect. Co., South Bend, Ind., U. S. A.		22,000		35		1	0000 A.C.S.R.	Unequal triangle	3'6"	3'6"				
137	Denver Transmission Co., Denver, Col., U. S. A.		15,000		11		1	#2, #4 A.C.S.R.	Triangle	3'0"					
138	Interstate Public Service Co., Indianapolis, Ind., U. S. A.		15,000		32		1	#2, #6 A.C.S.R.	Triangle	4'0"	3'0"				
139	Iowa Railway & Light Co., Cedar Rapids, Iowa, U. S. A		15,000		30		1	#2, #4 A.C.S.R.	Horizontal	1'5"					
140	Genessee Valley Pr. Co., Batavia, N. Y., U. S. A.		15,000		35		1	#2, #4 A.C.S.R.	Equilateral triangle	2'6"					
141	Hartford Elect. Lt. Co., Hartford, Conn., U. S. A	Hartford–South Manchester	11,000	60	7.4	1919	2	000 A.C.S.R.	Equilateral triangle	2'5"		20	22		6
142	Central Maine Pr. Co., Augusta, Maine, U. S. A.		11,000		40		1	#2 A.C.S.R.	Unequal triangle	3'6"	3'0"				
143	Pawnee Pr. & Water Co., Abilene, Kansas, U. S. A.		11,000		33		1	#2, #4 A.C.S.R.	Equilateral triangle	4'2"				30	
144	Rumford Falls Pr. Co., Rumford, Me., U. S. A.	Power Station–Oxford Mills	11,000	40	1	1922	1	500,000 C.M. A.C.S.R.	Unequal triangle	8'0"	6'0"				

DATA UPON HIGH VOLTAGE TRANSMISSION LINES (CONTINUED)

	SPANS				TOWERS				INSULATORS		GROUND WIRE	
									Straight Runs	Strain		
Ref. No.	Normal Span (Feet)	Maximum Span (Feet)	Normal Sag (Feet)	Normal Tension (Pounds)	Material of Towers	Material of Cross Arms	Material of Pins	Height of Lowest Conductor (Feet)	Number–Type	Number–Type	Material	Points Grounded
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
109	150		1.5		Wood	Wood	Steel		–Pin			
110	350	400	2.5	1450	Steel	Steel		31.5	1–2–Pin	4–Susp.	None	
111	175–250	800			Wood	Wood	Steel	30	1–Pin	4–Susp.	None	
112	328	820			Steel				–Pin			
113	150	900			Wood				–Pin			
114	300	325			Wood				–Pin			
115	320	1560			Wood				–Susp.			
116	350	350			Steel				–Pin–Susp.			
117	300	450			Steel				–Pin			
118	250	1400	2	1250	Wood	Wood	Steel	22	1–2–Pin	5–Susp.	5/6″ steel	Every pole
119	300	350			Wood				–Pin			
120	350		5.5	2100	Wood	Wood	Steel	29	1–Pin	3–Susp.	None	
121	210				Wood	Wood	C.I. and steel		–Pin	3–Susp.		
122					Wood	Wood		25	–Pin	3–Susp.	None	
123					Wood	Wood	Steel	27	–Pin	–Susp.	None	
124	130				Wood	Wood	Steel	27	–Pin	–Pin		
125	440	500			Wood				–Susp.			
126	225	250			Wood				–Pin			
127	200	400			Wood				–Pin			
128	200	500			Wood				–Pin			
129	160	810			Wood				–Pin			
130	220	900			Wood H frames				–Pin			
131	350	600			Wood				–Pin			
132	180	600			Wood				–Pin			
133	300	700			Wood				–Pin			
134	300	2300			Wood H frames				–Pin			
135	350	420			Steel				–Susp.			
136	175	200			Wood				–Pin			
137	110	300			Wood				–Pin			
138	200	225			Wood				–Pin			
139	200	250			Wood				–Pin			
140	175				Wood				–Pin			
141	125				Wood	Wood	Wood	31	–Pin	–Pin	None	None
142	200	800			Wood				–Pin			
143	310	400			Steel				–Pin			
144	600	650			Steel	Steel			2–Susp.	2 × 2–Susp.	3/8″ Siemens	

CHAPTER XXI

TABLES OF CONSTANTS

The tables of constants that follow comprise three groups. With one exception, as noted below, the tables are systematically arranged, all odd-numbered tables, on the left-hand pages, being for copper conductors and all even-numbered tables, on the right-hand pages, being for Aluminum Cable Steel Reinforced, the corresponding tables for copper and aluminum conductors facing one another throughout.

The stranding of copper conductors, as shown in Table I, under the heading of Standard Concentric Stranding is that designated as Standard by the Bureau of Standards (*Bulletin* No. 31) and recommended as standard by the A. I. E. E. for insulated cables for other than aerial use. The stranding used in the tables of constants, however, for sizes up to and including 1,000,000 circ. mils, is that recommended by the A. I. E. E.* as standard for cables for aerial use. Sizes larger than 1,000,000 circ. mils are rarely or never used in overhead transmission lines and for this reason the Bureau of Standards stranding of Table I is used in all tables for sizes above 1,000,000 circ. mils.

In the tables of physical characteristics and linear constants of A. C. S. R. conductors, it will be noted that certain circ. mil sizes are listed in duplicate; the difference between the two conductors being in the number of aluminum wires. For instance the 556,500 circ. mil conductor is listed with two different strandings, namely 30 aluminum, 7 steel and 26 aluminum, 7 steel. In the tables of auxiliary constants only one conductor of each circ. mil size is included and in all cases this is the conductor with the larger number of aluminum strands.

FUNDAMENTAL LINEAR CONSTANTS

Tables I to XXIV, inclusive, cover the physical characteristics and the values per mile of the fundamental linear constants of resistance, inductance, reactance, capacitance and capacity susceptance of stranded copper conductors and aluminum cable steel reinforced. Derived values of ratios of reactance to resistance and of charging kv.a. in three-phase circuits, at 25 and 60 cycles, respectively, are also included. An exception is Tables III and IV which show the resistance per 1,000 ft. of solid and stranded copper conductors, respectively. The various tables have been sufficiently described, under appropriate headings, in the preceding chapters.

TOTAL 60-CYCLE RESISTANCE AND TOTAL 60-CYCLE REACTANCE

In this group of tables, XXV to XXXIV, inclusive, are given directly the constants required in calculating the performance of short 60-cycle lines, up to 50 miles in length, for which lines the effect of capacity and the distributed nature of the constants can be neglected with small error. The tables show the total resistance and reactance, or impedance components, at 60 cycles, per conductor for circuits from 1 up to 50 miles in length. The values are tabulated at intervals of 1 mile for lines from 1 to 30 miles in length and at intervals of 2 miles for lines from 30 to 50 miles in length.

The copper tables include all standard gage and cir. mil sizes from No. 6 A.W.G. to 650,000 circ. mils, at nine different spacings from 2 to 8 ft., this range of spacings being sufficient for the voltages ordinarily used on lines of this class, except in the case of short branches from longer high tension circuits. In the aluminum tables are included only those sizes which are equivalent in conductivity (on the basis of copper 97 per cent and aluminum 61 per cent, as explained in the text), to the corresponding sizes of conductors in the copper tables. The resistance and reactance values for aluminum conductors are based on a current density of 600 amp. per square inch.

AUXILIARY CONSTANTS

In the third group of tables, numbers XXXV to XCVI, inclusive, are listed the values of the six components a_1 and a_2, b_1 and b_2, c_1 and c_2, respectively, of the auxiliary constants A, B and C which are used in the rigorous solution of long transmission lines, and the application of which has been fully treated in the preceding chapters.

The tables include constants for lines from 50 up to 300 miles in length. The constants are based upon a frequency of 60 cycles and resistance at 25°C. In the case of aluminum conductors, the resistance and reactance of which are affected by current density, the tables are based upon a density of 600 amp. per square inch. The constants were computed to four significant figures, the values being rounded off and tabulated to the nearest unit in the third figure An exception is the constant c_1, which, on account of its small value, has been tabulated to six decimal places.

With respect to conductor sizes and spacings used, the tables are divided into four groups with a progressive change in size and spacing with increase of length, the purpose being to prevent the tables from becoming unduly cumbersome and to eliminate impracticable combinations of conductor size and spacing in relation to length of line. The range of conductor size and spacing in the four groups is shown below:

*Column A, Table 904, A. I. E. E. "Standards," 1922, p. 103.

Length of Line, Mi.	Conductor Sizes: Copper Cm.	Aluminum, Cm.	Spacing, Ft.
50 to 70	# 6 to 650,000	#4 to 1,033,500	3 to 19
75 to 95	# 4 to 650,000	#2 to 1,192,500	5 to 21
100 to 190	# 2 to 650,000	#0 to 1,351,500	7 to 23
200 to 300	#00 to 1,000,000	#0000 to 1,590,000	9 to 25

The constants are tabulated at intervals of 5 miles from 50 miles up to and including 100 miles. Between 100 and 300 miles the intervals are increased to 10 miles thus giving a maximum increment of 10 per cent between any two consecutive distances. Each table contains the constants at nine different spacings at uniform intervals of 2 ft.

Interpolation of Constants.—While the constants are given at comparatively small intervals of distance, the actual length of line, in particular cases, will not usually correspond with the tabulated distances. Also the spacings, particularly the equivalent spacing as calculated for flat or unsymmetrical triangular arrangements of conductors, will in many cases fall between the table values. In such cases interpolation will be required for correct results. Since the constants for all standard sizes of copper conductors, within practical limits, as well as their aluminum equivalents, are tabulated, no interpolation for conductor sizes will ordinarily be required.

Interpolations for distance, made under conditions to produce the maximum error possible within the range of the tables, show that all of the constants can be interpolated, between any two successive table values of distance, by direct proportion of the tabular differences, with no error in the third significant figure. Thus, the constants for 105 miles can be accurately determined by adding to (or subtracting from, in the case of constant a_1) the constants at 100 miles one-half of the differences between the constants for 100 and 110 miles.

With respect to spacing, it is to be noted that, within the accuracy of three figure tables the constants a_1 and b_1 are independent of the spacing. The remaining constants can be interpolated, as with distance, by proportional differences, but with less accuracy, the possible error by this method being about 1 per cent. Exact interpolation, to three figures, can be made, however, in a very simple manner, as follows:

Constant a_2 is directly proportional, at a given distance, to the product of resistance and susceptance, or rb, and therefore, for a particular conductor, to the susceptance, b. This constant for any two spacings, therefore, is proportional to the susceptances at the two spacings. Similarly, the constant b_2 is proportional at a given distance, to the reactance, x, at the two spacings. c_1 is proportional to the product of resistance and the square of the susceptance, or, for a particular conductor to b^2, while constant c_2 is directly proportional to the susceptance, b.

Assume, for example, that it is required to determine the auxiliary constants of a 60-cycle circuit, 150 miles long, consisting of 000 copper conductors spaced 8 ft. apart. The constants for this circuit at 7 ft. spacing are found from Table LXV as follows: $a_1 = .952$, $a_2 = .0221$, $b_1 = 50.7$, $b_2 = 112$, $c_1 = -.000006$, $c_2 = .000844$.

From Tables XI and XXI are obtained the following values of the reactance x and susceptance, b, at 7 ft and 8 ft., respectively.

	At 7 Ft.	At 8 Ft.
Reactance, x	.754	.770
Susceptance, b	5.72	5.59

The constants at 8 ft. spacing are then found as below, the rigorous values to four figures (two for c_1) being also shown for comparison.

		Interpolated Value	Rigorous Value
a_1,	Same as at 7 ft. =	.952	.9515
a_2,	$.0221 \times \frac{5.59}{5.72}$ =	.0216	.02163
b_1,	Same as at 7 ft. =	50.7	50.75
b_2,	$112 \times \frac{.770}{.754}$ =	114.	114.1
c_1,	$-.000006 \times \frac{5.59^2}{.572^2}$ =	$-.000006$	$-.0000061$
c_2,	$.000844 \times \frac{5.59}{5.72}$ =	.000825	.0008251

It will be seen that the interpolated values are the same, to three figures, as the rigorous values as calculated by convergent series. As the constant c_1 is so small and unimportant its value can usually be neglected or interpolated by inspection, leaving only the constants a_2, b_2 and c_2 to be interpolated as shown.

An alternative to the above method, where exact interpolation for spacing is required, is the direct calculation of the constants by means of the simplified formulas given in the chapter following. By these formulas the constants are found directly in terms of numerical coefficients and simple functions of the fundamental linear constants r, x and b, formulas being given for frequencies of 25 and 50 cycles as well as 60 cycles.

In the actual design of a transmission circuit there are many factors which cause uncertainty as to the exact value of the fundamental constants upon which calculations should be based. The length of line is generally approximated from map locations in advance of actual survey and the increase of length due to sag is usually not taken into account. The resistance will vary with the conductivity of the conductor material and with temperature conditions due to location, altitude, hourly and seasonal variations of temperature, wind velocity, load current and other conditions. Reactance and susceptance will not correspond with theoretical values due to uncertainty as to the exact equivalent spacing of the conductors. It is evident, therefore, that with these numerous elements of uncertainty entering into the problem, the simple method of direct interpolation, both for distance and spacing, as given above, will yield all of the accuracy attainable in practice. It should be noted also, that while, as stated, direct interpolations for spacing are subject to a maximum error of 1 per cent the error in most cases will be much less than this. The more exact method of interpolation is, therefore, of academic, rather than practical interest.

TABLE I—PHYSICAL CHARACTERISTICS OF COPPER CONDUCTORS

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SOLID CONDUCTORS

Size of Conductor: Circular Mils	Size of Conductor: American Wire Gauge B&S	Cross Section Square Inches	Diameter in Inches	Weight in Pounds: Per 1000 Feet	Weight in Pounds: Per Mile	Feet per Pound	Breaking Weight, Hard Drawn: A. S. & W. Co.	Breaking Weight, Hard Drawn: Roebling	Breaking Weight, Annealed: A. S & W. Co.	Breaking Weight, Annealed: Roebling
211600	0000	.1662	.4600	640.5	3382.	1.561	8260.	8143.	5320.	5983.
167806	000	.1318	.4096	507.9	2682.	1.968	6550.	6722.	4220.	4755.
133077	00	.1045	.3648	402.8	2127.	2.482	5440.	5519.	3340.	3763.
105535	0	.08289	.3249	319.5	1687.	3.130	4530.	4517.	2650.	2984.
83693	1	.06573	.2893	253.3	1338.	3.947	3680.	3688.	2100.	2432.
66371	2	.05213	.2576	200.9	1061.	4.977	2970.	3003.	1670.	1929.
52635	3	.04134	.2294	159.3	841.2	6.276	2380.	2439.	1323.	1530.
41741	4	.03278	.2043	126.4	667.1	7.914	1900.	1970.	1050.	1213.
33102	5	.02600	.1819	100.2	529.1	9.980	1580.	1591.	884.	962.
26251	6	.02062	.1620	79.46	419.6	12.58	1300.	1280.	700.	763.
20818	7	.01635	.1443	63.02	332.7	15.87	1050.	1030.	556.	605.
16510	8	.01297	.1285	49.98	263.9	20.01	843.	826.	441.	480.
13093	9	.01028	.1144	39.63	209.3	25.23	678.	661.	350.	380.
10383	10	.008155	.1019	31.43	165.9	31.82	546.	529.	277.	314.
8234	11	.006467	.09074	24.92	131.6	40.12	343.	423.	174.	249.
6530	12	.005129	.08081	19.77	104.4	50.59	219.	337.	110.	197.
5178	13	.004067	.07196	15.68	82.76	63.80	138.	268.	68.9	157.
4107	14	.003225	.06408	12.43	65.64	80.44	86.7	214.	43.4	124.
3257	15	.002558	.05707	9.858	52.05	101.4	68.8	170.	34.4	98.
2583	16	.002028	.05082	7.818	41.28	127.9	54.7	135.	27.3	78.
2048	17	.001609	.04526	6.200	32.74	161.3		107.		62.
1624	18	.001276	.04030	4.917	25.96	203.4		85.		49.

STRANDED CONDUCTORS

Size of Conductor: Circular Mils	Size of Conductor: American Wire Gauge [illegible]	Cross Section Square Inches	Standard Concentric Stranding ★: Number of Wires	Standard Concentric Stranding ★: Diameter of Wires in Inches	Standard Concentric Stranding ★: Outside Diameter in Inches	Flexible Concentric Stranding: Number of Wires	Flexible Concentric Stranding: Diameter of Wires in Inches	Flexible Concentric Stranding: Outside Diameter in Inches	Weight in Pounds: Per 1000 Feet	Weight in Pounds: Per Mile	Feet per Pound
2000000		1.571	127	.1255	1.631	169	.1088	1.632	6180.	32600.	.162
1900000		1.492	127	.1223	1.590	169	.1060	1.590	5870.	31000.	.170
1800000		1.414	127	.1191	1.548	169	.1032	1.548	5560.	29300.	.180
1700000		1.335	127	.1157	1.504	169	.1003	1.504	5250.	27700.	.191
1600000		1.257	127	.1122	1.459	169	.0973	1.460	4940.	26100.	.202
1500000		1.178	91	.1284	1.412	127	.1087	1.413	4630.	24500.	.216
1400000		1.100	91	.1240	1.364	127	.1050	1.365	4320.	22800.	.231
1300000		1.021	91	.1195	1.315	127	.1012	1.315	4010.	21200.	.249
1200000		.9425	91	.1148	1.263	127	.0972	1.264	3710.	19600.	.270
1100000		.8639	91	.1099	1.209	127	.0931	1.210	3400.	17900.	.294
1000000		.7854	61	.1280	1.152	91	.1048	1.153	3090.	16300.	.324
950000		.7461	61	.1248	1.123	91	.1022	1.124	2930.	15500.	.341
900000		.7069	61	.1215	1.093	91	.0994	1.094	2780.	14700.	.360
850000		.6676	61	.1180	1.062	91	.0966	1.063	2620.	13900.	.381
800000		.6283	61	.1145	1.031	91	.0938	1.031	2470.	13000.	.405
750000		.5890	61	.1109	.998	91	.0908	.999	2320.	12200.	.432
700000		.5498	61	.1071	.964	91	.0877	.965	2160.	11400.	.463
650000		.5105	61	.1032	.929	91	.0845	.930	2010.	10600.	.498
600000		.4712	61	.0992	.893	91	.0812	.893	1850.	9780.	.540
550000		.4320	61	.0950	.855	91	.0777	.855	1700.	8970.	.589
500000		.3927	37	.1162	.814	61	.0905	.815	1540.	8150.	.648
450000		.3534	37	.1103	.772	61	.0859	.773	1390.	7340.	.720
400000		.3142	37	.1040	.728	61	.0810	.729	1240.	6520.	.810
350000		.2749	37	.0973	.681	61	.0757	.682	1080.	5710.	.925
300000		.2356	37	.0900	.630	61	.0701	.631	926.	4890.	1.04
250000		.1963	37	.0822	.575	61	.0640	.576	772.	4080.	1.30
211600	0000	.1662	19	.1055	.528	37	.0756	.533	653.	3450.	1.53
167806	000	.1318	19	.0940	.470	37	.0673	.471	518.	2740.	1.93
133077	00	.1045	19	.0837	.418	37	.0600	.420	411.	2170.	2.43
105535	0	.08289	19	.0745	.373	37	.0534	.374	326.	1720.	3.07
83693	1	.06573	19	.0664	.332	37	.0476	.333	258.	1360.	3.87
66371	2	.05213	7	.0974	.292	19	.0591	.296	205.	1080.	4.88
52635	3	.04134	7	0867	.260	19	.0526	.263	163.	858.	6.15
41741	4	.03278	7	.0772	.232	19	.0469	.234	129.	680.	7.76
33102	5	.02600	7	.0688	.206	19	.0417	.209	102.	540.	9.78
26251	6	.02062	7	.0612	.184	19	.0372	.186	81.0	428.	12.3

★ This stranding is designated as standard by the Bureau of Standards (Bulletin No. 31) and is recommended as standard by the A. I. E. E. for insulated cables for other than aerial use. For aerial use the A. I. E. E. recommends cables of a smaller number of strands and for this reason the following tables for copper conductors are based upon the latter stranding for sizes up to and including 1,000,000 C. M. |—as indicated on the tables.

TABLE II—PHYSICAL CHARACTERISTICS OF ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR		CROSS SECTION SQUARE INCHES	COPPER EQUIVALENT BASED UPON COPPER 97% ALUMIN. 61%	STRANDING		OUTSIDE DIAMETER IN INCHES	PER CENT WEIGHT		PER CENT AREA		ELASTIC LIMIT IN POUNDS	ULTIMATE STRENGTH IN POUNDS
CIRCULAR MILS (ALUMINUM)	A. W. G. OR B. & S.			ALUMINUM	STEEL		ALUMINUM	STEEL	ALUMINUM	STEEL		
1590000		1.249	1000000	54x.1716	7x.1716	1.544	72.8	27.2	88.5	11.5	38500	55900
1510500		1.186	950000	54x.1673	7x.1673	1.506	72.8	27.2	88.5	11.5	36600	53200
1431000		1.124	900000	54x.1628	7x.1628	1.465	72.8	27.2	88.5	11.5	34700	50300
1351500		1.061	850000	54x.1582	7x.1582	1.424	72.8	27.2	88.5	11.5	32700	47400
1272000		.9990	800000	54x.1535	7x.1535	1.382	72.8	27.2	88.5	11.5	30800	44600
1192500		.9366	750000	54x.1486	7x.1486	1.337	72.8	27.2	88.5	11.5	28800	41900
1113000		.8741	700000	54x.1436	7x.1436	1.292	72.8	27.2	88.5	11.5	26900	39000
1033500		.8117	650000	54x.1384	7x.1384	1.246	72.8	27.2	88.5	11.5	25000	36300
954000		.7493	600000	54x.1329	7x.1329	1.196	72.8	27.2	88.5	11.5	23100	33500
900000		.7069	566000	54x.1291	7x.1291	1.162	72.8	27.2	88.5	11.5	21800	31600
874500		.6868	550000	54x.1273	7x.1273	1.146	72.8	27.2	88.5	11.5	21200	30700
795000		.6244	500000	54x.1214	7x.1214	1.093	72.8	27.2	88.5	11.5	19250	27950
715500		.5620	450000	54x.1151	7x.1151	1.036	72.8	27.2	88.5	11.5	17360	25200
666600		.5235	419000	54x.1111	7x.1111	1.000	72.8	27.2	88.5	11.5	16180	23430
636000		.4995	400000	54x.1085	7x.1085	.977	72.8	27.2	88.5	11.5	15400	22300
605000		.4752	380500	54x.1059	7x.1059	.953	72.8	27.2	88.5	11.5	14675	21270
556500		.4371	350000	30x.1362	7x.1362	.953	59.9	40.1	81.1	18.9	19370	26800
556500		.4371	350000	26x.1463	7x.1090	.912	70.0	30.0	87.0	13.0	14600	20950
518000		.4068	326000	42x.1111	19x.1111	1.000	43.5	56.5	68.9	31.1	24000	33000
500000		.3927	314500	30x.1291	7x.1291	.904	59.9	40.1	81.1	18.9	17400	24080
477000		.3746	300000	30x.1261	7x.1261	.883	59.9	40.1	81.1	18.9	16600	23000
477000		.3746	300000	26x.1355	7x.1010	.845	70.0	30.0	87.0	13.0	12520	17950
397500		.3122	250000	30x.1151	7x.1151	.806	59.9	40.1	81.1	18.9	13800	19170
397500		.3122	250000	26x.1236	7x.0921	.771	70.0	30.0	87.0	13.0	10430	14960
336400		.2642	0000	30x.1059	7x.1059	.741	59.9	40.1	81.1	18.9	11715	16200
336400		.2642	0000	26x.1138	7x.0848	.710	70.0	30.0	87.0	13.0	8840	12660
300000		.2356	188800	30x.1000	7x.1000	.700	59.9	40.1	81.1	18.9	10440	14430
300000		.2356	188800	26x.1074	7x.0800	.670	70.0	30.0	87.0	13.0	7875	11280
266800		.2095	000	26x.1013	7x.0755	.632	70.0	30.0	87.0	13.0	7000	10040
266800		.2095	000	6x.2108	7x.0705	.633	72.8	27.2	88.5	11.5	6470	9385
211600	0000	.1662	00	6x.1880	1x.1880	.564	67.6	32.4	85.7	14.3	5940	8435
167806	000	.1318	0	6x.1670	1x.1670	.501	67.6	32.4	85.7	14.3	4690	6660
133077	00	.1045	1	6x.1490	1x.1490	.447	67.6	32.4	85.7	14.3	3730	5300
105535	0	.0829	2	6x.1327	1x.1327	.398	67.6	32.4	85.7	14.3	2960	4200
83693	1	.0657	3	6x.1182	1x.1182	.355	67.6	32.4	85.7	14.3	2355	3340
66371	2	.0521	4	6x.1052	1x.1052	.316	67.6	32.4	85.7	14.3	1860	2660
52635	3	.0413	5	6x.0938	1x.0938	.281	67.6	32.4	85.7	14.3	1480	2100
41741	4	.0328	6	6x.0834	1x.0834	.250	67.6	32.4	85.7	14.3	1170	1665
33102	5	.0260	7	6x.0743	1x.0743	.223	67.6	32.4	85.7	14.3	930	1315
26251	6	.0206	8	6x.0661	1x.0661	.198	67.6	32.4	85.7	14.3	735	1045

		WEIGHT IN POUNDS						LENGTH OF EACH PIECE IN FEET	NUMBER OF LENGTHS ON REEL	DIAMETER OF REEL IN INCHES	NUMBER POUNDS ON REEL
		PER 1000 FEET			PER MILE						
		TOTAL	ALUMINUM	STEEL	TOTAL	ALUMINUM	STEEL				
1590000		2047.0	1492.0	554.0	10808	7878	2925	2100	1	63	4300
1510500		1949.0	1421.0	528.0	10291	7503	2788	2200	1	63	4300
1431000		1841.0	1342.0	499.0	9722	7086	2635	2300	1	63	4260
1351500		1738.0	1267.0	471.0	9177	6690	2487	2450	1	63	4260
1272000		1637.0	1193.0	444.0	8643	6299	2344	2600	1	63	4260
1192500		1534.0	1118.0	416.0	8100	5903	2196	2800	1	63	4300
1113000		1432.0	1044.0	388.0	7561	5512	2049	3000	1	63	4300
1033500		1332.0	971.0	361.0	7030	5125	1905	3200	1	63	4265
954000		1229.0	896.0	333.0	6490	4730	1760	3500	1	63	4300
900000		1158.0	844.0	314.0	6120	4462	1658	3650	1	63	4230
874500		1125.0	820.0	305.0	5940	4330	1610	3800	1	63	4270
795000		1024.0	747.0	277.0	5407	3944	1463	4100	1	63	4200
715500		920.0	671.0	249.0	4857	3542	1315	4600	1	63	4230
666600		858.0	626.0	232.0	4530	3305	1225	4950	1	63	4250
636000		818.0	596.0	222.0	4320	3148	1172	5200	1	63	4250
605000		779.0	568.0	211.0	4113	2999	1114	5300	1	63	4130
556500		871.0	522.0	349.0	4595	2755	1840	3300	1	52	2875
556500		746.0	522.0	224.0	3938	2755	1183	2850	1		2125
518000		1116.0	486.0	630.0	5891	2566	3325	4950	1	63	4410
500000		783.0	469.0	314.0	4135	2477	1658	3650	1	52	2858
477000		747.0	447.5	299.5	3944	2362	1582	3900	1	52	2910
477000		639.5	447.5	192.0	3375	2362	1013	3350	1		2140
397500		622.0	373.0	249.0	3284	1969	1315	4600	1	52	2870
397500		532.6	373.0	159.6	2812	1969	843	4000	1		2130
336400		527.0	316.0	211.0	2783	1669	1114	5450	1	52	2872
336400		451.3	316.0	135.3	2384	1669	715	4700	1		2120
300000		469.7	281.4	188.3	2481	1486	995	6150	1	52	2890
300000		401.8	281.4	120.4	2122	1486	636	5350	1		2150
266800		357.2	250.0	107.2	1885	1319	566	6000	1		2143
266800		343.0	250.0	93.0	1811	1319	492	2700	1	40	926
211600	0000	295.0	199.5	96.0	1556	1052	504	3500	1	40	1033
167806	000	232.5	157.0	75.5	1227	830	397	4400	1	40	1023
133077	00	185.0	125.0	60.0	977	660	317	5600	1	40	1036
105535	0	147.0	99.5	47.5	776	525	251	3550	2	40	1044
83693	1	117.0	79.0	38.0	617	417	200	4450	2	40	1042
66371	2	92.4	62.5	29.9	488	330	158	5500	2	40	1015
52635	3	73.4	49.7	23.7	387	262	125	3550	4	40	1042
41741	4	58.0	39.3	18.7	306	207	99	4500	4	40	1044
33102	5	46.0	31.0	15.0	243	164	79	5500	4	40	1012
26251	6	36.4	24.6	11.8	192	130	62	7000	4	40	1020

TABLE III—RESISTANCE PER 1000 FEET

SOLID COPPER CONDUCTORS AT VARIOUS TEMPERATURES

FOR STRANDED CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR		DIAMETER IN INCHES AT 20°C	OHMS PER 1000 FEET OF SINGLE CONDUCTOR ★													
A. W. G. OR B. & S.	CIRCULAR MILS		ANNEALED COPPER—100% CONDUCTIVITY							HARD DRAWN COPPER—97.3% CONDUCTIVITY						
			0°C 32°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F	0°C 32°F	20°C 68°F	25°C 77°F	35°C 95°F	50°C 122°F	65°C 149°F	75°C 167°F
0000	211600.	.4600	.04516	.04901	.04998	.05190	.05479	.05768	.05961	.04652	.05037	.05133	.05326	.05615	.05903	.06096
000	167806.	.4096	.05695	.06180	.06302	.06545	.06909	.07273	.07516	.05867	.06352	.06473	.06716	.07080	.07444	.07686
00	133077.	.3648	.07181	.07793	.07947	.08253	.08712	.09172	.09478	.07398	.08010	.08162	.08468	.08927	.09386	.09692
0	105535.	.3249	.09055	.09827	.1002	.1041	.1099	.1157	.1195	.09328	.1010	.1029	.1068	.1126	.1184	.1222
1	83693.	.2893	.1142	.1239	.1264	.1312	.1385	.1458	.1507	.1176	.1274	.1298	.1347	.1420	.1492	.1541
2	66371.	.2576	.1440	.1563	.1593	.1655	.1747	.1839	.1900	.1483	.1606	.1637	.1698	.1790	.1882	.1943
3	52635.	.2294	.1816	.1970	.2009	.2087	.2203	.2319	.2396	.1870	.2025	.2064	.2141	.2257	.2373	.2451
4	41741.	.2043	.2289	.2485	.2533	.2631	.2778	.2924	.3022	.2358	.2554	.2602	.2700	.2846	.2993	.3090
5	33102.	.1819	.2887	.3133	.3195	.3318	.3502	.3687	.3810	.2974	.3220	.3281	.3404	.3589	.3773	.3896
6	26251.	.1620	.3640	.3951	.4028	.4184	.4416	.4649	.4805	.3750	.4060	.4138	.4293	.4526	.4758	.4913
7	20818.	.1443	.4590	.4982	.5080	.5275	.5569	.5863	.6059	.4729	.5120	.5218	.5413	.5707	.6000	.6196
8	16510.	.1285	.5788	.6282	.6405	.6652	.7023	.7393	.7640	.5963	.6456	.6579	.6826	.7196	.7566	.7813
9	13093.	.1144	.7299	.7921	.8077	.8388	.8855	.9322	.9633	.7519	.8141	.8297	.8607	.9074	.9540	.9851
10	10383.	.1019	.9203	.9989	1.018	1.058	1.117	1.175	1.215	.9481	1.027	1.046	1.085	1.144	1.203	1.242
11	8234.	.09074	1.161	1.260	1.284	1.334	1.408	1.482	1.532	1.196	1.294	1.319	1.369	1.443	1.517	1.566
12	6530.	.08081	1.463	1.588	1.619	1.682	1.775	1.869	1.931	1.508	1.632	1.663	1.726	1.819	1.913	1.975
13	5178.	.07196	1.845	2.003	2.042	2.121	2.239	2.357	2.436	1.901	2.058	2.098	2.176	2.294	2.412	2.491
14	4107.	.06408	2.327	2.525	2.575	2.674	2.823	2.972	3.071	2.397	2.595	2.645	2.744	2.893	3.042	3.141
15	3257.	.05707	2.934	3.184	3.247	3.372	3.560	3.748	3.873	3.023	3.273	3.335	3.460	3.648	3.835	3.960
16	2583.	.05082	3.700	4.016	4.094	4.252	4.489	4.726	4.884	3.812	4.127	4.206	4.363	4.600	4.836	4.994
17	2048.	.04526	4.666	5.064	5.163	5.362	5.660	5.959	6.158	4.806	5.204	5.303	5.502	5.800	6.099	6.297
18	1624.	.04030	5.883	6.385	6.510	6.761	7.138	7.514	7.765	6.061	6.562	6.687	6.938	7.314	7.690	7.941
19	1288.	.03589	7.418	8.051	8.210	8.526	9.001	9.475	9.792	7.642	8.275	8.433	8.749	9.223	9.697	10.01
20	1022.	.03196	9.355	10.15	10.35	10.75	11.35	11.95	12.35	9.637	10.43	10.63	11.03	11.63	12.23	12.63
21	810.1	.02846	11.80	12.80	13.05	13.56	14.31	15.07	15.57	12.15	13.16	13.41	13.91	14.66	15.42	15.92
22	642.4	.02535	14.87	16.14	16.46	17.09	18.05	19.00	19.63	15.32	16.59	16.91	17.54	18.49	19.44	20.08
23	509.5	.02257	18.76	20.36	20.76	21.56	22.76	23.96	24.76	19.32	20.92	21.32	22.12	23.32	24.52	25.32
24	404.0	.02010	23.65	25.67	26.17	27.18	28.70	30.21	31.22	24.37	26.38	26.88	27.89	29.40	30.92	31.92
25	320.4	.01790	29.82	32.37	33.00	34.27	36.18	38.09	39.36	30.72	33.27	33.90	35.17	37.08	38.98	40.25
26	254.1	.01594	37.61	40.81	41.62	43.22	45.63	48.03	49.64	38.74	41.95	42.75	44.35	46.75	49.16	50.76
27	201.5	.01420	47.42	51.47	52.48	54.50	57.53	60.57	62.59	48.85	52.89	53.90	55.93	58.96	61.99	64.01
28	159.8	.01264	59.80	64.90	66.17	68.72	72.55	76.37	78.93	61.60	66.70	67.97	70.52	74.34	78.16	80.71
29	126.7	.01126	75.40	81.83	83.44	86.66	91.48	96.30	99.52	77.68	84.10	85.71	88.93	93.74	98.56	101.8
30	100.5	.01003	95.08	103.2	105.2	109.3	115.4	121.4	125.5	97.95	106.1	108.1	112.1	118.2	124.3	128.3
31	79.70	.008928	119.9	130.1	132.7	137.8	145.5	153.1	158.2	123.5	133.7	136.3	141.4	149.1	156.7	161.8
32	63.21	.007950	151.2	164.1	167.3	173.7	183.4	193.1	199.5	155.7	168.6	171.9	178.3	188.0	197.6	204.1
33	50.13	.007080	190.6	206.9	211.0	219.1	231.3	243.5	251.6	196.4	212.6	216.7	224.8	237.0	249.2	257.3
34	39.75	.006305	240.4	260.9	266.0	276.3	291.7	307.0	317.3	247.6	268.1	273.3	283.5	298.9	314.2	324.5
35	31.52	.005615	303.1	329.0	335.5	348.4	367.8	387.2	400.1	312.3	338.1	344.6	357.5	376.9	396.2	409.2
36	25.00	.005000	382.2	414.8	423.0	439.3	463.7	488.2	504.5	393.8	426.4	434.5	450.8	475.2	499.6	515.9
37	19.83	.004453	482.0	523.1	533.4	553.9	584.8	615.6	636.2	496.5	537.6	547.9	568.4	599.2	630.0	650.6
38	15.72	.003965	607.8	659.6	672.6	698.5	737.4	776.3	802.2	626.1	677.9	690.9	716.8	755.6	794.5	820.4
39	12.47	.003531	766.4	831.8	848.1	880.8	929.8	978.9	1012.	789.5	854.8	871.2	903.8	952.8	1002.	1034.
40	9.888	.003145	966.5	1049.	1069.	1111.	1173.	1234.	1276.	995.6	1078.	1099.	1140.	1201.	1263.	1304.

★ Resistance at the stated temperature of a conductor whose length is 1000 feet at 20°C.

The above resistance values do not take into account skin effect, the maximum increase at 60 cycles within the range of the table being only 0.54 per cent. No allowance has been made for increased length due to sag when the conductors are suspended.

The 20°C temperature coefficient of resistance of annealed copper (100 per cent conductivity) is 0.00393 per degree C. For other conductivities the coefficient is proportional to the conductivity, being, for example, for hard drawn copper (97.3 per cent conductivity) $0.00393 \times .973 = 0.00382$. The fundamental resistivity used in calculating this table is the International Annealed Copper Standard, viz., 0.15328 ohm (meter, gram) at 20°C.

TABLE IV—RESISTANCE PER 1000 FEET

STRANDED COPPER CONDUCTORS AT VARIOUS TEMPERATURES

FOR SOLID CONDUCTORS SEE OPPOSITE PAGE

ANNEALED COPPER—100% CONDUCTIVITY

Size of Conductor		Outside Diam in Inches	Ohms per 1000 Feet of Single Conductor ★														
Circular Mils	A. W. G or B & S		0°C 32°F			25°C 77°F			35°C 95°F			65°C 149°F			75°C 167°F		
			D. C.	25 Cycles	60 Cycles	D. C.	25 Cycles	60 Cycles	D. C.	25 Cycles	60 Cycles	D. C.	25 Cycles	60 Cycles	D. C.	25 Cycles	60 Cycles
2000000		1.631	.004873	.005257	.006589	.005393	.005743	.007019	.005601	.005939	.007193	.006225	.006531	.007717	.006432	.006730	.007894
1900000		1.590	.005130	.005496	.006802	.005677	.006011	.007258	.005896	.006218	.007440	.006552	.006844	.007995	.006771	.007053	.008182
1800000		1.548	.005415	.005764	.007039	.005992	.006310	.007522	.006223	.006530	.007716	.006916	.007194	.008309	.007147	.007417	.008507
1700000		1.504	.005733	.006064	.007306	.006345	.006646	.007820	.006589	.006881	.008028	.007323	.007587	.008659	.007568	.007823	.008873
1600000		1.459	.006092	.006405	.007608	.006741	.007026	.008158	.007001	.007276	.008381	.007781	.008029	.009061	.008041	.008282	.009289
1500000		1.412	.006498	.006793	.007953	.007191	.007459	.008547	.007468	.007727	.008787	.008300	.008534	.009517	.008577	.008804	.009764
1400000		1.364	.006962	.007238	.008351	.007705	.007956	.008996	.008001	.008243	.009254	.008892	.009111	.01005	.009189	.009401	.01031
1300000		1.315	.007497	.007755	.008815	.008297	.008531	.009516	.008617	.008842	.009801	.009576	.009780	.01066	.009896	.01009	.01095
1200000		1.263	.008122	.008362	.009363	.008988	.009205	.01013	.009334	.009543	.01045	.01037	.01056	.01139	.01072	.01090	.01171
1100000		1.209	.008860	.009080	.01002	.009805	.01000	.01087	.01018	.01038	.01122	.01132	.01149	.01226	.01169	.01186	.01261
1000000		1.152	.009746	.009947	.01082	.01079	.01097	.01177	.01120	.01138	.01215	.01245	.01261	.01332	.01286	.01302	.01370
950000		1.123	.01026	.01045	.01129	.01135	.01153	.01230	.01179	.01196	.01270	.01310	.01326	.01393	.01354	.01369	.01434
900000		1.093	.01083	.01101	.01181	.01198	.01215	.01288	.01245	.01261	.01332	.01383	.01398	.01462	.01429	.01443	.01506
850000		1.062	.01147	.01164	.01240	.01269	.01284	.01354	.01318	.01333	.01400	.01465	.01478	.01540	.01513	.01526	.01586
800000		1.031	.01218	.01235	.01307	.01348	.01363	.01429	.01400	.01414	.01478	.01556	.01569	.01627	.01608	.01620	.01677
750000		.998	.01300	.01315	.01383	.01438	.01452	.01514	.01494	.01507	.01567	.01660	.01672	.01727	.01715	.01727	.01780
700000		.964	.01392	.01407	.01471	.01541	.01554	.01612	.01600	.01612	.01669	.01778	.01790	.01841	.01838	.01848	.01898
650000		.929	.01500	.01513	.01573	.01659	.01671	.01726	.01723	.01735	.01787	.01915	.01926	.01973	.01979	.01989	.02035
600000		.891	.01624	.01637	.01693	.01798	.01809	.01859	.01867	.01877	.01926	.02075	.02084	.02129	.02144	.02153	.02196
550000		.853	.01772	.01783	.01835	.01961	.01971	.02018	.02036	.02046	.02091	.02263	.02272	.02313	.02339	.02347	.02387
500000		.814	.01949	.01959	.02007	.02157	.02166	.02209	.02240	.02249	.02290	.02490	.02498	.02535	.02573	.02580	.02616
450000		.772	.02166	.02175	.02218	.02397	.02405	.02444	.02489	.02497	.02534	.02766	.02773	.02807	.02858	.02865	.02898
400000		.725	.02437	.02445	.02483	.02696	.02704	.02738	.02800	.02807	.02840	.03112	.03119	.03148	.03216	.03222	.03251
350000		.679	.02785	.02792	.02826	.03082	.03088	.03118	.03200	.03206	.03236	.03557	.03562	.03589	.03675	.03681	.03706
300000		.628	.03249	.03255	.03284	.03595	.03601	.03627	.03733	.03739	.03764	.04150	.04154	.04177	.04288	.04292	.04314
250000		.574	.03899	.03904	.03928	.04314	.04319	.04341	.04480	.04485	.04506	.04980	.04984	.05002	.05145	.05149	.05167
211600	0000	.522	.04606	.04611	.04631	.05097	.05101	.05120	.05293	.05297	.05315	.05883	.05887	.05903	.06079	.06082	.06098
167806	000	.464	.05809	.05812	.05828	.06428	.06431	.06446	.06675	.06677	.06692	.07419	.07421	.07434	.07666	.07668	.07681
133077	00	.414	.07325	.07327	.07340	.08105	.08108	.08120	.08417	.08419	.08430	.09355	.09357	.09367	.09666	.09668	.09678
105535	0	.368	.09237	.09238	.09249	.1022	.1022	.1023	.1061	.1062	.1063	.1180	.1180	.1181	.1219	.1219	.1220
83693	1	.328	.1165	.1165	.1166	.1289	.1289	.1290	.1338	.1339	.1339	.1488	.1488	.1488	.1537	.1537	.1538
66371	2	.292	.1469	.1469	.1469	.1625	.1626	.1626	.1688	.1688	.1688	.1876	.1876	.1877	.1938	.1938	.1939
52635	3	.260	.1852	.1852	.1853	.2050	.2050	.2050	.2128	.2128	.2129	.2366	.2366	.2366	.2444	.2444	.2445
41741	4	.232	.2335	.2335	.2336	.2584	.2584	.2585	.2684	.2684	.2684	.2983	.2983	.2983	.3082	.3082	.3082
33102	5	.206	.2945	.2945	.2945	.3259	.3259	.3259	.3384	.3384	.3384	.3761	.3761	.3762	.3886	.3886	.3887
26251	6	.184	.3714	.3714	.3714	.4110	.4110	.4110	.4267	.4267	.4268	.4743	.4743	.4743	.4901	.4901	.4901

HARD DRAWN COPPER—97.3% CONDUCTIVITY

2000000		1.631	.005021	.005394	.006712	.005540	.005881	.007143	.005747	.006077	.007317	.006370	.006670	.007841	.006578	.006869	.008016
1900000		1.590	.005285	.005641	.006930	.005831	.006157	.007385	.006050	.006364	.007570	.006706	.006991	.008126	.006924	.007202	.008315
1800000		1.548	.005579	.005918	.007177	.006155	.006465	.007660	.006386	.006686	.007856	.007078	.007351	.008449	.007309	.007572	.008647
1700000		1.504	.005907	.006228	.007451	.006517	.006811	.007967	.006762	.007046	.008176	.007495	.007752	.008809	.007739	.007988	.009023
1600000		1.459	.006276	.006581	.007764	.006925	.007203	.008317	.007184	.007453	.008541	.007963	.008207	.009219	.008223	.008459	.009449
1500000		1.412	.006694	.006982	.008120	.007387	.007647	.008716	.007664	.007915	.008959	.008494	.008723	.009689	.008771	.008993	.009938
1400000		1.364	.007172	.007442	.008532	.007914	.008158	.009179	.008211	.008447	.009439	.009101	.009314	.01023	.009397	.009605	.01050
1300000		1.315	.007724	.007975	.009013	.008523	.008751	.009717	.008842	.009062	.01000	.009800	.009999	.01087	.01012	.01031	.01116
1200000		1.263	.008367	.008600	.009580	.009232	.009444	.01035	.009579	.009783	.01067	.01062	.01080	.01161	.01096	.01114	.01193
1100000		1.209	.009128	.009342	.01026	.01007	.01027	.01111	.01045	.01064	.01146	.01158	.01175	.01251	.01196	.01212	.01286
1000000		1.152	.01004	.01024	.01109	.01108	.01126	.01204	.01149	.01166	.01242	.01274	.01289	.01359	.01316	.01331	.01398
950000		1.123	.01057	.01075	.01157	.01166	.01183	.01258	.01210	.01226	.01299	.01341	.01356	.01422	.01385	.01399	.01464
900000		1.093	.01116	.01133	.01211	.01231	.01247	.01319	.01277	.01293	.01362	.01416	.01430	.01493	.01462	.01475	.01537
850000		1.062	.01181	.01198	.01272	.01303	.01318	.01387	.01352	.01367	.01433	.01499	.01512	.01572	.01548	.01561	.01619
800000		1.031	.01255	.01271	.01341	.01385	.01399	.01464	.01437	.01451	.01513	.01593	.01605	.01662	.01645	.01657	.01712
750000		.998	.01339	.01354	.01420	.01477	.01491	.01552	.01533	.01546	.01605	.01699	.01710	.01763	.01754	.01766	.01817
700000		.964	.01434	.01448	.01511	.01583	.01595	.01652	.01642	.01654	.01709	.01820	.01831	.01881	.01879	.01890	.01939
650000		.929	.01545	.01558	.01616	.01705	.01716	.01770	.01768	.01779	.01831	.01960	.01970	.02017	.02024	.02034	.02079
600000		.891	.01673	.01685	.01740	.01847	.01857	.01907	.01916	.01926	.01974	.02123	.02133	.02176	.02193	.02202	.02244
550000		.853	.01826	.01837	.01887	.02014	.02024	.02070	.02090	.02099	.02143	.02316	.02325	.02365	.02392	.02400	.02439
500000		.814	.02008	.02018	.02064	.02216	.02225	.02266	.02299	.02307	.02348	.02548	.02556	.02592	.02631	.02639	.02674
450000		.772	.02231	.02240	.02282	.02462	.02470	.02508	.02554	.02562	.02598	.02831	.02838	.02871	.02923	.02930	.02962
400000		.725	.02510	.02518	.02555	.02770	.02777	.02810	.02873	.02880	.02913	.03185	.03191	.03221	.03289	.03295	.03323
350000		.679	.02869	.02876	.02908	.03165	.03172	.03201	.03284	.03290	.03319	.03640	.03646	.03671	.03759	.03764	.03789
300000		.628	.03347	.03353	.03381	.03693	.03699	.03724	.03831	.03837	.03861	.04247	.04252	.04274	.04385	.04390	.04411
250000		.574	.04016	.04021	.04045	.04432	.04436	.04458	.04598	.04602	.04623	.05096	.05100	.05119	.05262	.05266	.05284
211600	0000	.522	.04745	.04750	.04770	.05236	.05240	.05258	.05432	.05436	.05453	.06021	.06024	.06041	.06218	.06221	.06236
167806	000	.464	.05984	.05987	.06003	.06603	.06605	.06620	.06850	.06853	.06866	.07593	.07595	.07608	.07840	.07843	.07855
133077	00	.414	.07546	.07548	.07561	.08326	.08329	.08339	.08638	.08641	.08651	.09574	.09576	.09586	.09887	.09889	.09899
105535	0	.368	.09515	.09517	.09527	.1050	.1050	.1051	.1089	.1089	.1090	.1207	.1207	.1208	.1247	.1247	.1248
83693	1	.328	.1200	.1200	.1201	.1324	.1324	.1325	.1374	.1374	.1374	.1522	.1523	.1523	.1572	.1572	.1573
66371	2	.292	.1513	.1513	.1514	.1669	.1670	.1670	.1732	.1732	.1733	.1920	.1920	.1920	.1982	.1982	.1983
52635	3	.260	.1908	.1908	.1909	.2105	.2105	.2106	.2184	.2184	.2185	.2421	.2421	.2421	.2500	.2500	.2500
41741	4	.232	.2406	.2406	.2407	.2655	.2655	.2655	.2754	.2754	.2755	.3053	.3053	.3053	.3152	.3152	.3153
33102	5	.206	.3034	.3034	.3034	.3347	.3347	.3348	.3473	.3473	.3473	.3849	.3849	.3850	.3975	.3975	.3975
26251	6	.184	.3826	.3826	.3826	.4221	.4221	.4221	.4380	.4380	.4380	.4854	.4854	.4854	.5012	.5012	.5012

★ Resistance at the stated temperature of a conductor whose length is 1000 feet at 20°C.

No allowance has been made for increased length due to sag when the conductors are suspended. The resistance values are two per cent greater than for a solid rod of a cross section equal to the total cross section of the cable.

The 20°C temperature coefficient of resistance of annealed copper (100 per cent conductivity) is 0.00393 per degree C. For other conductivities the coefficient is proportional to the conductivity, being, for example, for hard drawn copper (97.3 per cent conductivity) 0.00393×.973=0.00382. The fundamental resistivity used in calculating this table is the International Annealed Copper Standard, viz., 0.15328 ohm (meter, gram) at 20°C.

TABLE V—RESISTANCE PER MILE

STRANDED COPPER CONDUCTORS AT VARIOUS TEMPERATURES

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

ANNEALED COPPER—100% CONDUCTIVITY

SIZE OF CONDUCTOR		OUTSIDE DIAM. IN INCHES	OHMS r PER MILE OF SINGLE CONDUCTOR ★														
			0°C 32°F			25°C 77°F			35°C 95°F			65°C 149°F			75°C 167°F		
CIRCULAR MILS	A. W. G. OR B & S		D. C.	25 CYCLES	60 CYCLES	D. C.	25 CYCLES	60 CYCLES	D. C.	25 CYCLES	60 CYCLES	D. C.	25 CYCLES	60 CYCLES	D. C.	25 CYCLES	60 CYCLES
2 000 000		1.631	.02573	.02776	.03479	.02848	.03032	.03706	.02957	.03136	.03798	.03287	.03448	.04074	.03396	.03553	.04168
1 900 000		1.590	.02709	.02902	.03592	.02997	.03174	.03832	.03113	.03283	.03929	.03460	.03614	.04222	.03575	.03724	.04320
1 800 000		1.548	.02859	.03043	.03717	.03164	.03332	.03972	.03286	.03448	.04074	.03652	.03799	.04387	.03774	.03916	.04492
1 700 000		1.504	.03027	.03202	.03857	.03350	.03509	.04129	.03479	.03633	.04239	.03867	.04006	.04572	.03996	.04131	.04685
1 600 000		1.459	.03217	.03382	.04017	.03560	.03710	.04308	.03697	.03842	.04425	.04108	.04239	.04784	.04245	.04373	.04904
1 500 000		1.412	.03431	.03587	.04199	.03797	.03938	.04513	.03943	.04080	.04640	.04382	.04506	.05025	.04529	.04649	.05155
1 400 000		1.364	.03676	.03822	.04409	.04068	.04201	.04750	.04225	.04353	.04887	.04695	.04811	.05304	.04852	.04964	.05445
1 300 000		1.315	.03959	.04095	.04654	.04381	.04504	.05024	.04550	.04669	.05175	.05056	.05164	.05630	.05225	.05329	.05784
1 200 000		1.263	.04289	.04415	.04944	.04746	.04860	.05350	.04929	.05039	.05515	.05477	.05577	.06014	.05660	.05756	.06182
1 100 000		1.209	.04678	.04794	.05291	.05177	.05282	.05740	.05377	.05478	.05922	.05975	.06067	.06474	.06175	.06263	.06659
1 000 000		1.152	.05146	.05252	.05713	.05695	.05791	.06215	.05915	.06007	.06418	.06573	.06656	.07031	.06792	.06873	.07236
950 000		1.123	.05417	.05518	.05959	.05994	.06085	.06492	.06226	.06313	.06707	.06919	.06998	.07356	.07150	.07227	.07574
900 000		1.093	.05718	.05814	.06237	.06328	.06414	.06802	.06572	.06656	.07030	.07303	.07378	.07720	.07547	.07620	.07951
850 000		1.062	.06054	.06145	.06548	.06700	.06781	.07150	.06958	.07037	.07394	.07733	.07804	.08129	.07991	.08060	.08374
800 000		1.031	.06433	.06518	.06900	.07118	.07196	.07546	.07393	.07467	.07806	.08216	.08282	.08590	.08490	.08556	.08853
750 000		.998	.06862	.06942	.07304	.07593	.07665	.07995	.07886	.07956	.08275	.08764	.08827	.09116	.09057	.09117	.09399
700 000		.964	.07352	.07427	.07766	.08135	.08203	.08513	.08449	.08514	.08813	.09390	.09449	.09719	.09703	.09760	.1002
650 000		.929	.07917	.07987	.08305	.08761	.08824	.09113	.09099	.09160	.09438	.1011	.1017	.1042	.1045	.1050	.1075
600 000		.891	.08576	.08641	.08937	.09491	.09549	.09817	.09857	.09913	.1017	.1095	.1100	.1124	.1132	.1137	.1160
550 000		.853	.09356	.09415	.09688	.1035	.1041	.1065	.1075	.1081	.1104	.1195	.1200	.1221	.1235	.1239	.1260
500 000		.814	.1029	.1035	.1060	.1139	.1144	.1166	.1183	.1188	.1209	.1315	.1319	.1338	.1358	.1362	.1381
450 000		.772	.1144	.1148	.1171	.1265	.1270	.1290	.1314	.1318	.1338	.1461	.1464	.1482	.1509	.1513	.1530
400 000		.725	.1286	.1291	.1311	.1424	.1427	.1446	.1479	.1482	.1500	.1643	.1647	.1662	.1698	.1701	.1717
350 000		.679	.1470	.1474	.1492	.1627	.1630	.1646	.1690	.1693	.1709	.1878	.1881	.1895	.1941	.1943	.1957
300 000		.628	.1715	.1719	.1734	.1898	.1901	.1915	.1972	.1974	.1988	.2191	.2193	.2206	.2264	.2267	.2278
250 000		.574	.2058	.2061	.2074	.2278	.2280	.2292	.2366	.2368	.2379	.2629	.2631	.2641	.2717	.2719	.2729
211 600	0000	.522	.2432	.2434	.2445	.2691	.2693	.2703	.2795	.2797	.2807	.3106	.3108	.3117	.3210	.3212	.3220
167 806	000	.464	.3067	.3069	.3077	.3394	.3395	.3403	.3525	.3526	.3534	.3917	.3918	.3925	.4048	.4049	.4056
133 077	00	.414	.3867	.3868	.3875	.4279	.4281	.4287	.4445	.4446	.4452	.4940	.4941	.4946	.5104	.5105	.5110
105 535	0	.368	.4877	.4878	.4883	.5396	.5397	.5402	.5605	.5605	.5610	.6229	.6229	.6234	.6436	.6437	.6441
83 693	1	.328	.6149	.6151	.6155	.6805	.6805	.6809	.7067	.7068	.7072	.7855	.7855	.7858	.8116	.8117	.8120
66 371	2	.292	.7754	.7755	.7758	.8581	.8582	.8584	.8912	.8913	.8916	.9905	.9906	.9908	1.024	1.024	1.024
52 635	3	.260	.9778	.9779	.9781	1.082	1.082	1.082	1.124	1.124	1.124	1.249	1.249	1.249	1.291	1.291	1.291
41 741	4	.232	1.233	1.233	1.233	1.364	1.364	1.365	1.417	1.417	1.417	1.575	1.575	1.575	1.627	1.627	1.628
33 102	5	.206	1.555	1.555	1.555	1.721	1.721	1.721	1.787	1.787	1.787	1.986	1.986	1.986	2.052	2.052	2.052
26 251	6	.184	1.961	1.961	1.961	2.170	2.170	2.170	2.253	2.253	2.254	2.505	2.505	2.505	2.588	2.588	2.588

HARD DRAWN COPPER—97.3% CONDUCTIVITY

CIRCULAR MILS	A. W. G. OR B & S	OUTSIDE DIAM. IN INCHES	0°C D. C.	0°C 25 CYCLES	0°C 60 CYCLES	25°C D. C.	25°C 25 CYCLES	25°C 60 CYCLES	35°C D. C.	35°C 25 CYCLES	35°C 60 CYCLES	65°C D. C.	65°C 25 CYCLES	65°C 60 CYCLES	75°C D. C.	75°C 25 CYCLES	75°C 60 CYCLES
2 000 000		1.631	.02651	.02848	.03544	.02925	.03105	.03771	.03035	.03209	.03863	.03364	.03522	.04140	.03473	.03627	.04233
1 900 000		1.590	.02790	.02978	.03659	.03079	.03251	.03899	.03194	.03360	.03997	.03541	.03691	.04291	.03656	.03803	.04390
1 800 000		1.548	.02945	.03125	.03789	.03250	.03414	.04045	.03372	.03530	.04148	.03737	.03881	.04461	.03859	.03998	.04565
1 700 000		1.504	.03119	.03289	.03934	.03441	.03596	.04207	.03570	.03720	.04317	.03957	.04093	.04651	.04086	.04218	.04764
1 600 000		1.459	.03314	.03475	.04099	.03656	.03803	.04392	.03793	.03935	.04510	.04205	.04333	.04868	.04342	.04466	.04989
1 500 000		1.412	.03535	.03686	.04287	.03900	.04038	.04602	.04046	.04179	.04730	.04485	.04606	.05116	.04631	.04748	.05247
1 400 000		1.364	.03787	.03929	.04505	.04179	.04308	.04847	.04335	.04460	.04984	.04805	.04918	.05403	.04962	.05072	.05544
1 300 000		1.315	.04078	.04211	.04759	.04500	.04621	.05131	.04669	.04785	.05281	.05175	.05280	.05737	.05343	.05446	.05891
1 200 000		1.263	.04418	.04541	.05058	.04875	.04987	.05466	.05058	.05165	.05632	.05606	.05703	.06131	.05789	.05883	.06300
1 100 000		1.209	.04819	.04932	.05418	.05318	.05421	.05868	.05517	.05616	.06051	.06115	.06204	.06603	.06315	.06401	.06789
1 000 000		1.152	.05301	.05404	.05854	.05850	.05943	.06358	.06069	.06159	.06555	.06727	.06808	.07175	.06946	.07025	.07382
950 000		1.123	.05580	.05678	.06110	.06158	.06246	.06643	.06388	.06474	.06858	.07080	.07158	.07509	.07312	.07387	.07728
900 000		1.093	.05890	.05984	.06396	.06500	.06584	.06963	.06743	.06825	.07192	.07474	.07547	.07881	.07718	.07789	.08114
850 000		1.062	.06237	.06325	.06718	.06882	.06961	.07323	.07140	.07217	.07566	.07914	.07983	.08301	.08172	.08239	.08548
800 000		1.031	.06627	.06709	.07082	.07312	.07388	.07729	.07586	.07659	.07989	.08408	.08474	.08774	.08683	.08746	.09038
750 000		.998	.07069	.07146	.07499	.07800	.07870	.08192	.08092	.08160	.08472	.08969	.09030	.09310	.09262	.09322	.09595
700 000		.964	.07573	.07646	.07977	.08357	.08423	.08725	.08670	.08734	.09024	.09609	.09667	.09931	.09923	.09979	.1024
650 000		.929	.08156	.08223	.08533	.08999	.09061	.09343	.09337	.09395	.09669	.1035	.1040	.1065	.1069	.1074	.1098
600 000		.891	.08835	.08898	.09185	.09749	.09806	.1007	.1011	.1017	.1042	.1121	.1126	.1149	.1158	.1162	.1185
550 000		.853	.09638	.09696	.09961	.1064	.1069	.1093	.1103	.1108	.1132	.1223	.1227	.1249	.1263	.1267	.1288
500 000		.814	.1060	.1066	.1090	.1170	.1175	.1197	.1214	.1218	.1239	.1345	.1349	.1369	.1389	.1393	.1412
450 000		.772	.1178	.1183	.1205	.1300	.1304	.1324	.1348	.1352	.1372	.1495	.1498	.1516	.1543	.1547	.1564
400 000		.725	.1325	.1330	.1349	.1462	.1466	.1484	.1517	.1521	.1538	.1682	.1685	.1700	.1736	.1739	.1755
350 000		.679	.1515	.1518	.1536	.1671	.1675	.1690	.1734	.1737	.1752	.1922	.1925	.1938	.1984	.1987	.2000
300 000		.628	.1767	.1770	.1785	.1950	.1953	.1966	.2023	.2026	.2039	.2242	.2245	.2256	.2315	.2318	.2329
250 000		.574	.2121	.2123	.2136	.2340	.2342	.2354	.2427	.2430	.2441	.2691	.2693	.2702	.2778	.2780	.2790
211 600	0000	.522	.2506	.2508	.2518	.2765	.2767	.2776	.2868	.2870	.2879	.3179	.3181	.3189	.3282	.3284	.3292
167 806	000	.464	.3159	.3161	.3170	.3486	.3488	.3495	.3617	.3618	.3625	.4009	.4010	.4017	.4139	.4140	.4147
133 077	00	.414	.3984	.3985	.3992	.4396	.4398	.4403	.4560	.4562	.4567	.5055	.5056	.5061	.5219	.5220	.5226
105 535	0	.368	.5024	.5025	.5030	.5544	.5545	.5549	.5751	.5752	.5757	.6374	.6375	.6379	.6582	.6582	.6586
83 693	1	.328	.6335	.6336	.6340	.6991	.6991	.6995	.7252	.7252	.7256	.8038	.8039	.8042	.8300	.8300	.8303
66 371	2	.292	.7988	.7989	.7992	.8815	.8816	.8819	.9144	.9145	.9148	1.014	1.014	1.014	1.047	1.047	1.047
52 635	3	.260	1.007	1.007	1.008	1.112	1.112	1.112	1.153	1.153	1.153	1.278	1.278	1.278	1.320	1.320	1.320
41 741	4	.232	1.270	1.270	1.271	1.402	1.402	1.402	1.454	1.454	1.454	1.612	1.612	1.612	1.664	1.664	1.665
33 102	5	.206	1.602	1.602	1.602	1.768	1.768	1.768	1.834	1.834	1.834	2.032	2.032	2.033	2.099	2.099	2.099
26 251	6	.184	2.020	2.020	2.020	2.229	2.229	2.229	2.312	2.312	2.312	2.563	2.563	2.563	2.647	2.647	2.647

★ Resistance at the stated temperature of a conductor whose length is one mile at 20°C.

No allowance has been made for increased length due to sag when the conductors are suspended. The resistance values are two per cent greater than for a solid rod of a cross section equal to the total cross section of the cable.

The 20°C temperature coefficient of resistance of annealed copper (100 per cent conductivity) is 0.00393 per degree C. For other conductivities the coefficient is proportional to the conductivity, being, for example, for hard drawn copper (97.3 per cent conductivity) 0.00393 × .973 = 0.00382. The fundamental resistivity used in calculating this table is the International Annealed Copper Standard, viz., 0.15328 ohm (meter, gram) at 20°C.

TABLE VI—RESISTANCE PER MILE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR: CIRCULAR MILS (ALUMINUM)	SIZE OF CONDUCTOR: AMERICAN WIRE GAUGE B&S	NUMBER OF LAYERS OF ALUMINUM OVER STEEL CORE	NUMBER OF WIRES: ALUM	NUMBER OF WIRES: STEEL	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	D. C. RESISTANCE IN OHMS PER MILE AT 0 AMPERES AND 25° C.	OHMS r PER MILE OF SINGLE CONDUCTOR AT 25° C.: 1 0 AMPERES PER SQUARE INCH			200 AMPERES PER SQUARE INCH			400 AMPERES PER SQUARE INCH			600 AMPERES PER SQUARE INCH		
							[illegible] CYCLES	[illegible] CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	60 CYCLES
1 590000		3	54	7	1000000	.0587	.0588	.0590	.0591	.0589	.0592	.0594	.0590	.0595	.0598	.0592	.0602	.0607
1 510500		3	54	7	950000	.0618	.0619	.0621	.0622	.0620	.0623	.0625	.0621	.0626	.0629	.0623	.0632	.0637
1 431000		3	54	7	900000	.0652	.0653	.0655	.0656	.0654	.0658	.0659	.0655	.0661	.0663	.0657	.0666	.0671
1 351500		3	54	7	850000	.0691	.0692	.0694	.0695	.0693	.0696	.0698	.0694	.0699	.0702	.0695	.0705	.0709
1 272000		3	54	7	800000	.0734	.0735	.0737	.0738	.0736	.0740	.0742	.0737	.0743	.0746	.0738	.0748	.0752
1 192500		3	54	7	750000	.0783	.0784	.0786	.0788	.0785	.0789	.0791	.0786	.0792	.0795	.0787	.0796	.0801
1 113000		3	54	7	700000	.0839	.0840	.0842	.0844	.0841	.0845	.0848	.0842	.0849	.0852	.0843	.0853	.0857
1 033500		3	54	7	650000	.0903	.0905	.0907	.0909	.0906	.0910	.0913	.0907	.0913	.0917	.0908	.0918	.0922
954000		3	54	7	600000	.0979	.0980	.0981	.0982	.0980	.0983	.0985	.0981	.0986	.0989	.0983	.0992	.0997
900000		3	54	7	566000	.104	.104	.104	.104	.104	.104	.105	.104	.105	.105	.104	.105	.106
874500		3	54	7	550000	.107	.107	.107	.108	.107	.107	.108	.107	.108	.109	.107	.108	.109
795000		3	54	7	500000	.117	.118	.118	.119	.118	.119	.119	.118	.119	.119	.118	.119	.119
715500		3	54	7	450000	.131	.131	.131	.132	.131	.132	.133	.131	.132	.133	.131	.132	.133
666600		3	54	7	419000	.140	.140	.141	.141	.140	.141	.142	.140	.141	.142	.141	.142	.142
636000		3	54	7	400000	.147	.147	.148	.148	.147	.148	.149	.147	.148	.149	.147	.149	.149
605000		3	54	7	380500	.154	.155	.155	.155	.155	.155	.156	.155	.156	.156	.155	.156	.157
556500		2	30	7	350000	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168
556500		2	26	7	350000	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168	.168
518000		2	42	19	326000	.180	.180	.180	.180	.180	.180	.180	.180	.180	.180	.180	.180	.180
500000		2	30	7	314500	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187
477000		2	30	7	300000	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196
477000		2	26	7	300000	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196
397500		2	30	7	250000	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235
397500		2	26	7	250000	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235
336400		2	30	7	0000	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278
336400		2	26	7	0000	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278
300000		2	30	7	188800	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311
300000		2	26	7	188800	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311
266800		2	26	7	000	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350
266800		1	6	7	000	.350	.350	.351	.351	.350	.351	.352	.351	.353	.355	.353	.360	.363
211600	0000	1	6	1	00	.441	.442	.444	.445	.443	.445	.446	.444	.450	.453	.447	.458	.464
167806	000	1	6	1	0	.556	.557	.559	.560	.557	.560	.561	.560	.566	.569	.562	.574	.579
133077	00	1	6	1	1	.702	.702	.704	.706	.703	.705	.707	.704	.709	.712	.706	.714	.718
105535	0	1	6	1	2	.885	.885	.887	.888	.885	.888	.889	.886	.890	.892	.887	.891	.893
83693	1	1	6	1	3	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12
66371	2	1	6	1	4	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41
52635	3	1	6	1	5	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78
41741	4	1	6	1	6	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
33102	5	1	6	1	7	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82
26251	6	1	6	1	8	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56

							800 AMPERES PER SQUARE INCH			1000 AMPERES PER SQUARE INCH			1200 AMPERES PER SQUARE INCH			1400 AMPERES PER SQUARE INCH		
							25 CYCLES	[illegible] CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	60 CYCLES	25 CYCLES	50 CYCLES	[illegible] CYCLES
1 590000		3	54	7	1 000000	.0587	.0595	.0611	.0619	.0600	.0625	.0638	.0606	.0643	.0662	.0615	.0670	.0698
1 510500		3	54	7	950000	.0618	.0626	.0642	.0650	.0630	.0655	.0668	.0636	.0672	.0691	.0645	.0698	.0726
1 431000		3	54	7	900000	.0652	.0660	.0676	.0684	.0665	.0690	.0703	.0670	.0706	.0724	.0678	.0730	.0756
1 351500		3	54	7	850000	.0691	.0698	.0713	.0721	.0703	.0728	.0740	.0708	.0743	.0761	.0715	.0765	.0790
1 272000		3	54	7	800000	.0734	.0741	.0756	.0764	.0746	.0770	.0782	.0751	.0785	.0802	.0757	.0805	.0829
1 192500		3	54	7	750000	.0783	.0790	.0804	.0812	.0794	.0818	.0830	.0799	.0832	.0849	.0805	.0851	.0874
1 113000		3	54	7	700000	.0839	.0846	.0860	.0867	.0850	.0873	.0885	.0855	.0887	.0903	.0860	.0904	.0927
1 033500		3	54	7	650000	.0903	.0910	.0924	.0931	.0914	.0935	.0945	.0919	.0950	.0965	.0924	.0967	.0988
954000		3	54	7	600000	.0979	.0986	.100	.101	.0990	.101	.102	.0994	.102	.104	.0998	.104	.106
900000		3	54	7	566000	.104	.104	.106	.107	.105	.107	.108	.105	.108	.110	.106	.110	.112
874500		3	54	7	550000	.107	.107	.109	.110	.108	.110	.111	.108	.111	.113	.109	.113	.115
795000		3	54	7	500000	.117	.118	.119	.120	.118	.120	.121	.119	.121	.123	.119	.123	.125
715500		3	54	7	450000	.131	.131	.133	.133	.131	.133	.134	.132	.135	.136	.133	.137	.139
666600		3	54	7	419000	.140	.141	.143	.143	.141	.145	.144	.142	.145	.146	.142	.146	.148
636000		3	54	7	400000	.147	.148	.149	.150	.148	.151	.152	.149	.152	.154	.149	.153	.156
605000		3	54	7	380500	.154	.155	.157	.158	.156	.159	.160	.156	.160	.162	.157	.161	.163
556500		2	30	7	350000	.168	.168	.168	.168	.168	.169	.169	.169	.169	.169	.169	.169	.169
556500		2	26	7	350000	.168	.168	.168	.168	.168	.169	.169	.169	.169	.169	.169	.169	.169
518000		2	42	19	326000	.180	.180	.180	.180	.180	.181	.181	.181	.181	.181	.181	.181	.181
500000		2	30	7	314500	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187	.187
477000		2	30	7	300000	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196
477000		2	26	7	300000	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196	.196
397500		2	30	7	250000	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235
397500		2	26	7	250000	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235	.235
336400		2	30	7	0000	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278
336400		2	26	7	0000	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278	.278
300000		2	30	7	188800	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311
300000		2	26	7	188800	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311	.311
266800		2	26	7	000	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350	.350
266800		1	6	7	000	.350	.359	.378	.388	.368	.406	.425	.378	.434	.463	.384	.454	.489
211600	0000	1	6	1	00	.441	.452	.474	.485	.458	.493	.510	.463	.508	.530	.468	.521	.548
167806	000	1	6	1	0	.556	.566	.584	.594	.570	.597	.611	.574	.610	.628	.579	.624	.647
133077	00	1	6	1	1	.702	.708	.721	.727	.711	.730	.739	.715	.742	.756	.720	.758	.777
105535	0	1	6	1	2	.885	.888	.895	.899	.890	.901	.907	.893	.911	.920	.898	.927	.941
83693	1	1	6	1	3	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.12	1.14	1.15	1.13	1.16	1.17
66371	2	1	6	1	4	1.41	1.41	1.41	1.41	1.41	1.42	1.42	1.41	1.43	1.43	1.42	1.44	1.45
52635	3	1	6	1	5	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.79	1.79	1.78	1.80	1.80
41741	4	1	6	1	6	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
33102	5	1	6	1	7	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82
26251	6	1	6	1	8	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56

The D. C. resistances above are calculated values based upon a conductivity of 61 per cent at 20° C. and a constant mass temperature coefficient of resistance at 20° C. of .0039. The resistances are based upon the aluminum cross section only, no account being taken of the conductance of the steel core. Two per cent has been added to allow for increase in length due to spiral stranding. No allowance has been made for increased length due to sag when the conductors are suspended.

The 60 cycle resistances are based upon actual tests made on various sizes of cable at various current densities. The 25 and 50 cycle resistances were calculated on the assumption that the increase of resistance for alternating current over that for direct current varies as the 1.5 power of the frequency.

TABLE VII—INDUCTANCE PER MILE OF SINGLE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	INDUCTANCE L IN MILLIHENRIES PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S			2 INCHES (5.1 CM.)	4 INCHES (10.2 CM.)	6 INCHES (15.2 CM.)	8 INCHES (20.3 CM.)	10 INCHES (25.4 CM.)	12 INCHES (30.5 CM.)	15 INCHES (38.1 CM.)	18 INCHES (45.7 CM.)	21 INCHES (53.3 CM.)	24 INCHES (61.0 CM.)	27 INCHES (68.6 CM.)	30 INCHES (76.2 CM.)	33 INCHES (83.8 CM.)	36 INCHES (91.4 CM.)
2000000		127	1.631	.3705	.5936	.7241	.8167	.8885	.9472	1.019	1.078	1.127	1.170	1.208	1.242	1.273	1.301
1900000		127	1.590	.3787	.6018	.7323	.8249	.8968	.9554	1.027	1.086	1.136	1.179	1.216	1.250	1.281	1.309
1800000		127	1.548	.3874	.6105	.7410	.8336	.9055	.9641	1.036	1.095	1.144	1.187	1.225	1.259	1.290	1.318
1700000		127	1.504	.3966	.6197	.7502	.8428	.9147	.9733	1.045	1.104	1.153	1.196	1.234	1.268	1.299	1.327
1600000		127	1.459	.4064	.6295	.7600	.8526	.9244	.9831	1.055	1.114	1.163	1.206	1.244	1.278	1.309	1.337
1500000		91	1.412	.4174	.6405	.7710	.8636	.9355	.9941	1.066	1.125	1.174	1.217	1.255	1.289	1.320	1.348
1400000		91	1.364	.4285	.6516	.7821	.8747	.9466	1.005	1.077	1.136	1.185	1.228	1.266	1.300	1.331	1.359
1300000		91	1.315	.4405	.6636	.7941	.8867	.9585	1.017	1.089	1.148	1.197	1.240	1.278	1.312	1.343	1.371
1200000		91	1.263	.4533	.6765	.8070	.8995	.9714	1.030	1.102	1.161	1.210	1.253	1.291	1.325	1.356	1.384
1100000		91	1.209	.4674	.6905	.8210	.9136	.9854	1.044	1.116	1.175	1.224	1.267	1.305	1.339	1.370	1.398
1000000		61	1.152	.4838	.7069	.8374	.9300	1.002	1.061	1.132	1.191	1.241	1.284	1.322	1.355	1.386	1.414
950000		61	1.123	.4921	.7152	.8457	.9383	1.010	1.069	1.141	1.199	1.249	1.292	1.330	1.364	1.394	1.422
900000		61	1.093	.5008	.7239	.8544	.9470	1.019	1.077	1.149	1.208	1.258	1.301	1.338	1.372	1.403	1.431
850000		61	1.062	.5100	.7331	.8636	.9562	1.028	1.087	1.159	1.217	1.267	1.310	1.348	1.382	1.412	1.440
800000		61	1.031	.5197	.7428	.8733	.9659	1.038	1.096	1.168	1.227	1.277	1.320	1.357	1.391	1.422	1.450
750000		61	.998	.5301	.7532	.8837	.9763	1.048	1.107	1.179	1.237	1.287	1.330	1.368	1.402	1.432	1.460
700000		61	.964	.5412	.7643	.8948	.9874	1.059	1.118	1.190	1.248	1.298	1.341	1.379	1.413	1.444	1.472
650000		61	.929	.5532	.7763	.9068	.9994	1.071	1.130	1.202	1.260	1.310	1.353	1.391	1.425	1.455	1.483
600000		37	.891	.5683	.7914	.9219	1.014	1.086	1.145	1.217	1.275	1.325	1.368	1.406	1.440	1.471	1.499
550000		37	.853	.5823	.8054	.9359	1.028	1.100	1.159	1.231	1.289	1.339	1.382	1.420	1.454	1.485	1.513
500000		37	.814	.5976	.8207	.9512	1.044	1.116	1.174	1.246	1.305	1.354	1.397	1.435	1.469	1.500	1.528
450000		37	.772	.6146	.8377	.9682	1.061	1.133	1.191	1.263	1.322	1.371	1.414	1.452	1.486	1.517	1.545
400000		19	.725	.6388	.8619	.9924	1.085	1.157	1.216	1.287	1.346	1.396	1.439	1.477	1.510	1.541	1.569
350000		19	.679	.6603	.8834	1.014	1.107	1.178	1.237	1.309	1.368	1.417	1.460	1.498	1.532	1.563	1.591
300000		19	.628	.6851	.9082	1.039	1.131	1.203	1.262	1.334	1.392	1.442	1.485	1.523	1.557	1.587	1.615
250000		19	.574	.7145	.9376	1.068	1.161	1.232	1.291	1.363	1.422	1.471	1.514	1.552	1.586	1.617	1.645
211600	0000	7	.522	.7590	.9821	1.113	1.205	1.277	1.336	1.408	1.466	1.516	1.559	1.597	1.631	1.661	1.689
167806	000	7	.464	.7963	1.019	1.150	1.243	1.314	1.373	1.445	1.504	1.553	1.596	1.634	1.668	1.699	1.727
133077	00	7	.414	.8336	1.057	1.187	1.280	1.352	1.410	1.482	1.541	1.590	1.633	1.671	1.705	1.736	1.764
105535	0	7	.368	.8709	1.094	1.225	1.317	1.389	1.448	1.519	1.578	1.628	1.671	1.709	1.743	1.773	1.801
83693	1	7	.328	.9082	1.131	1.262	1.354	1.426	1.485	1.557	1.615	1.665	1.708	1.746	1.780	1.811	1.839
66371	2	7	.292	.9456	1.169	1.299	1.392	1.464	1.522	1.594	1.653	1.702	1.745	1.783	1.817	1.848	1.876
52635	3	7	.260	.9829	1.206	1.338	1.429	1.501	1.560	1.631	1.690	1.740	1.783	1.821	1.855	1.885	1.913
41741	4	7	.232	1.020	1.243	1.374	1.466	1.538	1.597	1.669	1.727	1.777	1.820	1.858	1.892	1.923	1.951
33102	5	7	.206	1.058	1.281	1.411	1.504	1.576	1.634	1.706	1.765	1.814	1.857	1.895	1.929	1.960	1.988
26251	6	7	.184	1.095	1.318	1.448	1.541	1.613	1.672	1.743	1.802	1.852	1.895	1.933	1.966	1.997	2.025

		DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M.)	23 FEET (7.01 M.)	25 FEET (7.62 M.)	30 FEET (9.14 M.)	35 FEET (10.67 M.)
2000000		1.350	1.393	1.465	1.524	1.574	1.617	1.654	1.719	1.773	1.819	1.859	1.895	1.927	1.956	1.983	2.042	2.092
1900000		1.359	1.402	1.473	1.532	1.582	1.625	1.663	1.727	1.781	1.827	1.867	1.903	1.935	1.965	1.992	2.050	2.100
1800000		1.367	1.410	1.482	1.541	1.590	1.633	1.671	1.736	1.790	1.836	1.876	1.912	1.944	1.973	2.000	2.059	2.109
1700000		1.377	1.420	1.491	1.550	1.600	1.643	1.681	1.745	1.799	1.845	1.885	1.921	1.953	1.983	2.009	2.068	2.118
1600000		1.386	1.429	1.501	1.560	1.609	1.652	1.690	1.755	1.809	1.855	1.895	1.931	1.963	1.992	2.019	2.078	2.127
1500000		1.397	1.440	1.512	1.571	1.620	1.663	1.701	1.766	1.820	1.866	1.906	1.942	1.974	2.003	2.030	2.089	2.139
1400000		1.408	1.451	1.523	1.582	1.632	1.675	1.712	1.777	1.831	1.877	1.917	1.953	1.985	2.014	2.041	2.100	2.150
1300000		1.420	1.463	1.535	1.594	1.643	1.686	1.724	1.789	1.843	1.889	1.929	1.965	1.997	2.026	2.053	2.112	2.162
1200000		1.433	1.476	1.548	1.607	1.656	1.699	1.737	1.802	1.856	1.902	1.942	1.978	2.010	2.039	2.066	2.125	2.174
1100000		1.447	1.490	1.562	1.621	1.670	1.713	1.751	1.816	1.870	1.916	1.956	1.992	2.024	2.053	2.080	2.139	2.188
1000000		1.464	1.507	1.579	1.637	1.687	1.730	1.768	1.832	1.886	1.932	1.972	2.008	2.040	2.070	2.097	2.155	2.205
950000		1.472	1.515	1.587	1.645	1.695	1.738	1.776	1.841	1.894	1.940	1.981	2.017	2.049	2.078	2.105	2.164	2.213
900000		1.481	1.524	1.596	1.654	1.704	1.747	1.785	1.849	1.903	1.949	1.989	2.025	2.057	2.087	2.114	2.172	2.222
850000		1.490	1.533	1.605	1.663	1.713	1.756	1.794	1.858	1.912	1.958	1.999	2.034	2.067	2.096	2.123	2.181	2.231
800000		1.500	1.543	1.614	1.673	1.723	1.766	1.804	1.868	1.922	1.968	2.008	2.044	2.076	2.106	2.133	2.191	2.241
750000		1.510	1.553	1.625	1.684	1.733	1.776	1.814	1.879	1.932	1.978	2.019	2.055	2.087	2.116	2.143	2.202	2.251
700000		1.521	1.564	1.636	1.695	1.744	1.787	1.825	1.890	1.944	1.990	2.030	2.066	2.098	2.127	2.154	2.213	2.262
650000		1.533	1.576	1.648	1.707	1.756	1.799	1.837	1.902	1.955	2.002	2.042	2.078	2.110	2.139	2.166	2.225	2.274
600000		1.548	1.591	1.663	1.722	1.771	1.814	1.852	1.917	1.971	2.017	2.057	2.093	2.125	2.154	2.181	2.240	2.289
550000		1.562	1.605	1.677	1.736	1.785	1.828	1.866	1.931	1.985	2.031	2.071	2.107	2.139	2.168	2.195	2.254	2.303
500000		1.578	1.621	1.692	1.751	1.801	1.844	1.882	1.946	2.000	2.046	2.086	2.122	2.154	2.184	2.210	2.269	2.319
450000		1.595	1.637	1.709	1.768	1.818	1.861	1.898	1.963	2.017	2.063	2.103	2.139	2.171	2.200	2.227	2.286	2.336
400000		1.619	1.662	1.734	1.792	1.842	1.885	1.923	1.987	2.041	2.087	2.127	2.163	2.195	2.225	2.252	2.310	2.360
350000		1.640	1.683	1.755	1.814	1.863	1.906	1.944	2.009	2.063	2.109	2.149	2.185	2.217	2.246	2.273	2.332	2.381
300000		1.665	1.708	1.780	1.839	1.888	1.931	1.969	2.034	2.087	2.133	2.174	2.210	2.242	2.271	2.298	2.357	2.406
250000		1.694	1.737	1.809	1.868	1.918	1.960	1.998	2.063	2.117	2.163	2.203	2.239	2.271	2.300	2.327	2.386	2.436
211600	0000	1.739	1.782	1.854	1.912	1.962	2.005	2.043	2.108	2.161	2.207	2.248	2.283	2.316	2.345	2.372	2.430	2.480
167806	000	1.776	1.819	1.891	1.950	1.999	2.042	2.080	2.145	2.199	2.245	2.285	2.321	2.353	2.382	2.409	2.468	2.517
133077	00	1.814	1.857	1.928	1.987	2.037	2.080	2.118	2.182	2.236	2.282	2.322	2.358	2.390	2.420	2.446	2.505	2.555
105535	0	1.851	1.894	1.966	2.024	2.074	2.117	2.155	2.219	2.273	2.319	2.360	2.395	2.428	2.457	2.484	2.542	2.592
83693	1	1.888	1.931	2.003	2.062	2.111	2.154	2.192	2.257	2.311	2.357	2.397	2.433	2.465	2.494	2.521	2.580	2.629
66371	2	1.926	1.968	2.040	2.099	2.149	2.192	2.230	2.294	2.348	2.394	2.434	2.470	2.502	2.532	2.558	2.617	2.667
52635	3	1.963	2.006	2.078	2.136	2.186	2.229	2.267	2.331	2.385	2.431	2.472	2.507	2.540	2.569	2.596	2.654	2.704
41741	4	2.000	2.043	2.115	2.174	2.223	2.266	2.304	2.369	2.422	2.469	2.509	2.545	2.577	2.606	2.633	2.692	2.741
33102	5	2.037	2.080	2.152	2.211	2.261	2.304	2.341	2.406	2.460	2.506	2.546	2.582	2.614	2.643	2.670	2.729	2.779
26251	6	2.075	2.118	2.190	2.248	2.298	2.341	2.379	2.443	2.497	2.543	2.583	2.619	2.651	2.681	2.708	2.766	2.816

The table values were derived from formulae of H. B. Dwight which accurately take into account the effect of stranding. For concentric stranding the inductance, which varies with the number of strands in the conductor, is as follows, the diameter d of the conductor being expressed, for convenience, in terms of circular mils and D being expressed in inches. The inductance L in millihenries per mile is

For 7 strands	For 19 strands	For 37 strands	For 61 strands	For 91 strands	For 127 strands
$0.74113 \log_{10} \frac{2431\,D}{\sqrt{C.M.}}$	$0.74113 \log_{10} \frac{2301\,D}{\sqrt{C.M.}}$	$0.74113 \log_{10} \frac{2263\,D}{\sqrt{C.M.}}$	$0.74113 \log_{10} \frac{2248\,D}{\sqrt{C.M.}}$	$0.74113 \log_{10} \frac{2240\,D}{\sqrt{C.M.}}$	$0.74113 \log_{10} \frac{2235\,D}{\sqrt{C.M.}}$

The inductance L' for any spacing D' not given in the table is equal to the inductance L at the NEXT SMALLER spacing D given in the table plus the quantity $0.74113 \log_{10} D'/D$. Thus $L'=L+0.74113 \log_{10} D'/D$. Or the inductance in millihenries to be added to that at the next smaller spacing may be taken from table below.

D′/D	1·05	1·10	1·15	1·20	1·25	1·30	1·35	1·40	1·45	1·50	1·55	1·60	1·65	1·70	1·75	1·80	1·85	1·90	1·95	2·00
L +	·0157	·0307	·0450	·0587	·0718	·0844	·0966	·1083	·1196	·1305	·1411	·1513	·1612	·1708	·1801	·1892	·1980	·2066	·2150	·2231

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE VIII—INDUCTANCE PER MILE OF SINGLE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

INDUCTANCE L IN MILLIHENRIES PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

MULTIPLE LAYER CONDUCTORS—ALL CURRENT DENSITIES

Circular mils or A. W. G. (B. & S.) (Aluminum)	Number of wires: Aluminum	Number of wires: Steel	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	2 feet (0.61 M.)	2.5 feet (0.76 M.)	3 feet (0.91 M.)	3.5 feet (1.07 M.)	4 feet (1.22 M.)	5 feet (1.52 M.)	6 feet (1.83 M.)	7 feet (2.13 M.)	8 feet (2.44 M.)	9 feet (2.74 M.)	11 feet (3.35 M.)	13 feet (3.96 M.)	15 feet (4.57 M.)	17 feet (5.18 M.)	[illegible] feet (5.79 M.)	[illegible] feet (6.40 M.)	23 feet (7.0 M.)	25 feet (7.62 M.)	30 feet (9.14 M.)	35 feet (10.67 M.)
1 590 000	54	7	1 000 000	1.13	1.20	1.26	1.31	1.35	1.42	1.48	1.53	1.58	1.61	1.68	1.73	1.78	1.82	1.85	1.89	1.92	1.94	2.00	2.05
1 510 500	54	7	950 000	1.14	1.21	1.27	1.32	1.36	1.43	1.49	1.54	1.58	1.62	1.68	1.74	1.78	1.82	1.86	1.89	1.92	1.95	2.01	2.06
1 431 000	54	7	900 000	1.14	1.22	1.27	1.32	1.37	1.44	1.50	1.55	1.59	1.63	1.69	1.75	1.79	1.83	1.87	1.90	1.93	1.96	2.02	2.06
1 351 500	54	7	850 000	1.15	1.22	1.28	1.33	1.37	1.45	1.51	1.55	1.60	1.64	1.70	1.75	1.80	1.84	1.88	1.91	1.94	1.96	2.02	2.07
1 272 000	54	7	800 000	1.16	1.23	1.29	1.34	1.38	1.46	1.51	1.56	1.61	1.65	1.71	1.76	1.81	1.85	1.89	1.92	1.95	1.97	2.03	2.08
1 192 500	54	7	750 000	1.17	1.24	1.30	1.35	1.39	1.47	1.52	1.57	1.62	1.66	1.72	1.77	1.82	1.86	1.90	1.93	1.96	1.98	2.04	2.09
1 113 000	54	7	700 000	1.18	1.25	1.31	1.36	1.40	1.48	1.53	1.58	1.63	1.66	1.73	1.78	1.83	1.87	1.91	1.94	1.97	1.99	2.05	2.10
1 033 500	54	7	650 000	1.19	1.26	1.32	1.37	1.41	1.49	1.55	1.60	1.64	1.68	1.74	1.79	1.84	1.88	1.92	1.95	1.98	2.00	2.06	2.11
954 000	54	7	600 000	1.20	1.28	1.34	1.39	1.43	1.50	1.56	1.61	1.65	1.69	1.75	1.81	1.85	1.89	1.93	1.96	1.99	2.02	2.08	2.13
900 000	54	7	566 000	1.21	1.29	1.34	1.39	1.44	1.51	1.57	1.62	1.66	1.70	1.76	1.82	1.86	1.90	1.94	1.97	2.00	2.03	2.08	2.13
874 500	54	7	550 000	1.22	1.29	1.35	1.40	1.44	1.51	1.57	1.62	1.66	1.70	1.77	1.82	1.87	1.91	1.94	1.97	2.00	2.03	2.09	2.14
795 000	54	7	500 000	1.23	1.30	1.36	1.41	1.46	1.53	1.59	1.64	1.68	1.72	1.78	1.84	1.88	1.92	1.96	1.99	2.02	2.05	2.10	2.15
715 500	54	7	450 000	1.25	1.32	1.38	1.43	1.47	1.54	1.60	1.65	1.70	1.73	1.80	1.85	1.90	1.94	1.97	2.01	2.04	2.06	2.12	2.17
666 600	54	7	419 000	1.26	1.33	1.39	1.44	1.48	1.56	1.62	1.66	1.71	1.75	1.81	1.86	1.91	1.95	1.99	2.02	2.05	2.07	2.13	2.18
636 000	54	7	400 000	1.27	1.34	1.40	1.45	1.49	1.56	1.62	1.67	1.71	1.75	1.82	1.87	1.92	1.96	1.99	2.03	2.05	2.08	2.14	2.19
605 000	54	7	380 500	1.28	1.35	1.41	1.46	1.50	1.57	1.63	1.68	1.72	1.76	1.83	1.88	1.93	1.97	2.00	2.03	2.06	2.09	2.15	2.20
556 500	30	7	350 000	1.28	1.35	1.41	1.46	1.50	1.57	1.63	1.68	1.72	1.76	1.83	1.88	1.93	1.97	2.00	2.03	2.06	2.09	2.15	2.20
556 500	26	7	350 000	1.29	1.36	1.42	1.47	1.51	1.59	1.65	1.69	1.74	1.78	1.84	1.89	1.94	1.98	2.02	2.05	2.08	2.10	2.16	2.21
518 000	42	19	326 000	1.26	1.33	1.39	1.44	1.48	1.56	1.62	1.66	1.71	1.75	1.81	1.86	1.91	1.95	1.99	2.02	2.05	2.07	2.13	2.18
500 000	30	7	314 500	1.29	1.37	1.42	1.47	1.52	1.59	1.65	1.70	1.74	1.78	1.84	1.90	1.94	1.98	2.02	2.05	2.08	2.11	2.17	2.21
477 000	30	7	300 000	1.30	1.37	1.43	1.48	1.52	1.60	1.66	1.70	1.75	1.79	1.85	1.90	1.95	1.99	2.03	2.06	2.09	2.11	2.17	2.22
477 000	26	7	300 000	1.32	1.39	1.45	1.50	1.54	1.61	1.67	1.72	1.76	1.80	1.87	1.92	1.97	2.01	2.04	2.07	2.10	2.13	2.19	2.24
397 500	30	7	250 000	1.33	1.41	1.46	1.51	1.56	1.63	1.69	1.74	1.78	1.82	1.88	1.94	1.98	2.02	2.06	2.09	2.12	2.15	2.21	2.25
397 500	26	7	250 000	1.35	1.42	1.48	1.53	1.57	1.64	1.70	1.75	1.79	1.83	1.90	1.95	2.00	2.04	2.07	2.11	2.13	2.16	2.22	2.27
336 400	30	7	0 000	1.36	1.43	1.49	1.54	1.58	1.66	1.72	1.76	1.81	1.85	1.91	1.96	2.01	2.05	2.09	2.12	2.15	2.17	2.23	2.28
336 400	26	7	0 000	1.38	1.45	1.51	1.56	1.60	1.67	1.73	1.78	1.82	1.86	1.93	1.98	2.03	2.07	2.10	2.13	2.16	2.19	2.25	2.30
300 000	30	7	188 800	1.38	1.45	1.51	1.56	1.60	1.68	1.74	1.78	1.83	1.87	1.93	1.98	2.03	2.07	2.11	2.14	2.17	2.19	2.25	2.30
300 000	26	7	188 800	1.40	1.47	1.53	1.58	1.62	1.69	1.75	1.80	1.84	1.88	1.95	2.00	2.05	2.09	2.12	2.15	2.18	2.21	2.27	2.32
266 800	26	7	000	1.41	1.48	1.54	1.59	1.64	1.71	1.77	1.82	1.86	1.90	1.96	2.02	2.06	2.10	2.14	2.17	2.20	2.23	2.28	2.33

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 0 AMPERES PER SQUARE INCH

Circular mils or A. W. G. (B. & S.) (Aluminum)	Number of wires: Aluminum	Number of wires: Steel	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	2 feet (0.61 M.)	2.5 feet (0.76 M.)	3 feet (0.91 M.)	3.5 feet (1.07 M.)	4 feet (1.22 M.)	5 feet (1.52 M.)	6 feet (1.83 M.)	7 feet (2.13 M.)	8 feet (2.44 M.)	9 feet (2.74 M.)	11 feet (3.35 M.)	13 feet (3.96 M.)	15 feet (4.57 M.)	17 feet (5.18 M.)	[illegible] feet (5.79 M.)	[illegible] feet (6.40 M.)	23 feet (7.0 M.)	25 feet (7.62 M.)	30 feet (9.14 M.)	35 feet (10.67 M.)
266 800	6	7	000	1.46	1.53	1.59	1.64	1.68	1.76	1.81	1.86	1.91	1.94	2.01	2.06	2.11	2.15	2.19	2.22	2.25	2.27	2.33	2.38
0 000	6	1	00	1.61	1.68	1.74	1.79	1.84	1.91	1.97	2.02	2.06	2.10	2.16	2.22	2.26	2.30	2.34	2.37	2.40	2.43	2.48	2.53
000	6	1	0	1.66	1.73	1.79	1.84	1.88	1.95	2.01	2.06	2.10	2.14	2.20	2.26	2.30	2.34	2.38	2.41	2.44	2.47	2.53	2.58
00	6	1	1	1.69	1.77	1.82	1.87	1.92	1.99	2.05	2.10	2.14	2.18	2.24	2.30	2.34	2.38	2.42	2.45	2.48	2.51	2.57	2.61
0	6	1	2	1.73	1.80	1.86	1.91	1.95	2.02	2.08	2.13	2.18	2.21	2.28	2.33	2.38	2.42	2.45	2.49	2.52	2.54	2.60	2.65
1	6	1	3	1.76	1.83	1.89	1.94	1.99	2.06	2.12	2.17	2.21	2.25	2.31	2.37	2.41	2.45	2.49	2.52	2.55	2.58	2.63	2.68
2	6	1	4	1.79	1.87	1.93	1.97	2.02	2.09	2.15	2.20	2.24	2.28	2.34	2.40	2.44	2.48	2.52	2.55	2.58	2.61	2.67	2.72
3	6	1	5	1.83	1.90	1.96	2.01	2.05	2.12	2.18	2.23	2.27	2.31	2.38	2.43	2.48	2.52	2.55	2.58	2.61	2.64	2.70	2.75
4	6	1	6	1.86	1.93	1.99	2.04	2.08	2.16	2.21	2.26	2.31	2.34	2.41	2.46	2.51	2.55	2.59	2.62	2.65	2.67	2.73	2.78
5	6	1	7	1.89	1.97	2.02	2.07	2.12	2.19	2.25	2.30	2.34	2.38	2.44	2.50	2.54	2.58	2.62	2.65	2.68	2.71	2.77	2.81
6	6	1	8	1.93	2.00	2.06	2.11	2.15	2.22	2.28	2.33	2.38	2.41	2.48	2.53	2.58	2.62	2.65	2.69	2.72	2.74	2.80	2.85

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 600 AMPERES PER SQUARE INCH

Circular mils or A. W. G. (B. & S.) (Aluminum)	Number of wires: Aluminum	Number of wires: Steel	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	2 feet (0.61 M.)	2.5 feet (0.76 M.)	3 feet (0.91 M.)	3.5 feet (1.07 M.)	4 feet (1.22 M.)	5 feet (1.52 M.)	6 feet (1.83 M.)	7 feet (2.13 M.)	8 feet (2.44 M.)	9 feet (2.74 M.)	11 feet (3.35 M.)	13 feet (3.96 M.)	15 feet (4.57 M.)	17 feet (5.18 M.)	[illegible] feet (5.79 M.)	[illegible] feet (6.40 M.)	23 feet (7.0 M.)	25 feet (7.62 M.)	30 feet (9.14 M.)	35 feet (10.67 M.)
266 800	6	7	000	1.51	1.58	1.64	1.69	1.73	1.80	1.86	1.91	1.95	1.99	2.06	2.11	2.16	2.20	2.23	2.26	2.29	2.32	2.38	2.43
0 000	6	1	00	1.67	1.74	1.80	1.85	1.89	1.96	2.02	2.07	2.11	2.15	2.21	2.27	2.31	2.35	2.39	2.42	2.45	2.48	2.54	2.59
000	6	1	0	1.69	1.76	1.82	1.87	1.92	1.99	2.05	2.10	2.14	2.18	2.24	2.30	2.34	2.38	2.42	2.45	2.48	2.51	2.56	2.61
00	6	1	1	1.72	1.79	1.85	1.90	1.94	2.02	2.07	2.12	2.17	2.20	2.27	2.32	2.37	2.41	2.45	2.48	2.51	2.53	2.59	2.64
0	6	1	2	1.75	1.82	1.88	1.93	1.97	2.04	2.10	2.15	2.19	2.23	2.30	2.35	2.40	2.44	2.47	2.51	2.53	2.56	2.62	2.67
1	6	1	3	1.78	1.85	1.91	1.96	2.00	2.07	2.13	2.18	2.22	2.26	2.33	2.38	2.43	2.47	2.50	2.54	2.56	2.59	2.65	2.70
2	6	1	4	1.81	1.88	1.94	1.99	2.03	2.10	2.16	2.21	2.25	2.29	2.36	2.41	2.46	2.50	2.53	2.56	2.59	2.62	2.68	2.73
3	6	1	5	1.83	1.91	1.97	2.01	2.06	2.13	2.19	2.24	2.28	2.32	2.38	2.44	2.48	2.52	2.56	2.59	2.62	2.65	2.71	2.76
4	6	1	6	1.86	1.94	1.99	2.04	2.09	2.16	2.22	2.27	2.31	2.35	2.41	2.47	2.51	2.55	2.59	2.62	2.65	2.68	2.74	2.78
5	6	1	7	1.90	1.97	2.03	2.08	2.12	2.19	2.25	2.30	2.34	2.38	2.45	2.50	2.55	2.59	2.62	2.66	2.68	2.71	2.77	2.82
6	6	1	8	1.94	2.01	2.07	2.12	2.16	2.23	2.29	2.34	2.38	2.42	2.49	2.54	2.59	2.63	2.66	2.69	2.72	2.75	2.81	2.86

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 1200 AMPERES PER SQUARE INCH

Circular mils or A. W. G. (B. & S.) (Aluminum)	Number of wires: Aluminum	Number of wires: Steel	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	2 feet (0.61 M.)	2.5 feet (0.76 M.)	3 feet (0.91 M.)	3.5 feet (1.07 M.)	4 feet (1.22 M.)	5 feet (1.52 M.)	6 feet (1.83 M.)	7 feet (2.13 M.)	8 feet (2.44 M.)	9 feet (2.74 M.)	11 feet (3.35 M.)	13 feet (3.96 M.)	15 feet (4.57 M.)	17 feet (5.18 M.)	[illegible] feet (5.79 M.)	[illegible] feet (6.40 M.)	23 feet (7.0 M.)	25 feet (7.62 M.)	30 feet (9.14 M.)	35 feet (10.67 M.)
266 800	6	7	000	1.72	1.79	1.85	1.90	1.94	2.01	2.07	2.12	2.16	2.20	2.27	2.32	2.37	2.41	2.44	2.48	2.50	2.53	2.59	2.64
0 000	6	1	00	1.74	1.81	1.87	1.92	1.96	2.03	2.09	2.14	2.18	2.22	2.29	2.34	2.39	2.43	2.46	2.50	2.52	2.55	2.61	2.66
000	6	1	0	1.77	1.84	1.90	1.95	2.00	2.07	2.13	2.18	2.22	2.26	2.32	2.38	2.42	2.46	2.50	2.53	2.56	2.59	2.64	2.69
00	6	1	1	1.80	1.87	1.93	1.98	2.02	2.09	2.15	2.20	2.24	2.28	2.35	2.40	2.45	2.49	2.52	2.55	2.58	2.61	2.67	2.72
0	6	1	2	1.82	1.89	1.95	2.00	2.04	2.11	2.17	2.22	2.26	2.30	2.36	2.42	2.46	2.50	2.54	2.57	2.60	2.63	2.69	2.74
1	6	1	3	1.83	1.90	1.96	2.00	2.05	2.13	2.19	2.23	2.28	2.32	2.38	2.43	2.48	2.52	2.56	2.59	2.62	2.64	2.70	2.75
2	6	1	4	1.84	1.92	1.97	2.01	2.07	2.14	2.20	2.25	2.29	2.33	2.39	2.45	2.49	2.53	2.57	2.60	2.63	2.66	2.72	2.76
3	6	1	5	1.86	1.93	1.99	2.04	2.08	2.15	2.21	2.26	2.30	2.34	2.41	2.46	2.51	2.55	2.58	2.61	2.64	2.67	2.73	2.78
4	6	1	6	1.87	1.94	2.00	2.05	2.10	2.17	2.23	2.28	2.32	2.36	2.42	2.48	2.52	2.56	2.60	2.63	2.66	2.69	2.74	2.79
5	6	1	7	1.92	1.99	2.05	2.10	2.14	2.21	2.27	2.32	2.36	2.40	2.46	2.52	2.56	2.60	2.64	2.67	2.70	2.73	2.79	2.84
6	6	1	8	1.95	2.02	2.08	2.13	2.17	2.25	2.30	2.35	2.40	2.43	2.50	2.55	2.60	2.64	2.68	2.71	2.74	2.76	2.82	2.87

By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The inductance values of the table are based upon actual tests on various sizes of cable at various current densities at one foot spacing. The inductances at other spacings were calculated from those at one foot spacing by means of the fundamental inductance formula.

The inductance L' for any spacing D' not given in the table is equal to the inductance L at the next smaller spacing D given in the table plus the quantity $0.74113 \log_{10} D'/D$. Thus $L' = L + 0.74113 \log_{10} D'/D$. Or the inductance in millihenries to be added to that at the next smaller spacing may be taken from table below.

D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
L +	.016	.031	.045	.059	.072	.084	.097	.108	.120	.131	.141	.151	.161	.171	.180	.189	.198	.207	.215	.223

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

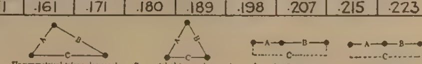


TABLE IX—25 CYCLE REACTANCE PER MILE OF SINGLE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	25 CYCLE REACTANCE X IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.) DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE (B&S)			2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
2000000		127	1.631	.0582	.0932	.114	.128	.140	.149	.160	.169	.177	.184	.190	.195	.200	.204
1900000		127	1.590	.0595	.0945	.115	.130	.141	150	.161	.171	.178	.185	191	.196	.201	.206
1800000		127	1.548	.0609	.0959	116	.131	.142	.151	.163	.172	180	186	.192	.198	.203	.207
1700000		127	1.504	.0623	.0973	.118	.132	.144	.153	.164	173	.181	.188	.194	.199	.204	.208
1600000		127	1.459	.0638	.0989	.119	.134	.145	.154	.166	.175	.183	.189	.195	.201	.206	210
1500000		91	1.412	.0656	.100	.121	.136	.147	.156	.167	177	.184	.191	.197	.202	.207	.212
1400000		91	1.364	.0673	.102	.123	.137	.149	.158	.169	.178	.186	.193	199	.204	.209	.213
1300000		91	1.315	.0692	.104	.125	.139	.151	.160	.171	.180	.188	.195	.201	.206	.211	.215
1200000		91	1.263	.0712	.106	.127	.141	.153	.162	.173	.182	.190	.197	.203	.208	.213	.217
1100000		91	1.209	.0734	.108	.129	.144	.155	.164	.175	.185	.192	.199	.205	.210	.215	.220
1000000		61	1.152	.0760	.111	.132	.146	.157	.167	.178	.187	.195	.202	.208	.213	.218	.222
950000		61	1.123	.0773	.112	.133	.147	159	.168	.179	.188	196	.203	.209	.214	.219	223
900000		61	1.093	.0787	.114	.134	.149	.160	.169	.181	.190	.198	.204	.210	.216	.220	.225
850000		61	1.062	.0801	.115	.136	.150	.161	.171	.182	.191	.199	.206	.212	.217	.222	.226
800000		61	1.031	.0816	.117	.137	.152	.163	.172	.184	.193	.201	.207	.213	.219	.223	.228
750000		61	.998	.0833	.118	.139	.153	.165	.174	.185	.194	.202	.209	.215	.220	.225	.229
700000		61	.964	.0850	.120	.141	.155	.166	.176	.187	.196	.204	.211	.217	.222	.227	.231
650000		61	.929	.0869	.122	.142	.157	.168	.177	.189	.198	.206	.213	.218	.224	.229	.233
600000		37	.891	.0893	.124	.145	.159	.171	.180	.191	.200	.208	.215	.221	.226	.231	.235
550000		37	.853	.0915	.127	.147	.162	.173	.182	.193	.203	.210	.217	.223	.228	.233	.238
500000		37	.814	.0939	.129	.149	.164	.175	.184	.196	.205	.213	.220	.225	.231	.236	.240
450000		37	.772	.0965	.132	.152	.167	.178	.187	.198	.208	.215	.222	.228	.233	.238	.243
400000		19	.725	.100	.135	.156	.170	.182	.191	.202	.211	.219	.226	.232	.237	.242	.246
350000		19	.679	.104	.139	.159	.174	.185	.194	.206	.215	.223	.229	.235	.241	.245	.250
300000		19	.628	.108	.143	.163	.178	.189	.198	.209	.219	.227	.233	.239	.245	.249	.254
250000		19	.574	.112	.147	.168	.182	.194	.203	.214	.223	.231	.238	.244	.249	.254	.258
211600	0000	7	.522	.119	.154	.175	189	.201	.210	.221	.230	.238	.245	.251	.256	.261	.265
167806	000	7	.464	.125	.160	.181	.195	.206	.216	.227	.236	.244	.251	.257	.262	.267	.271
133077	00	7	.414	.131	.166	.186	.201	.212	.222	.233	.242	.250	.257	.263	.268	.273	.277
105535	0	7	.368	.137	.172	.192	.207	.218	.227	.239	.248	.256	.262	.268	.274	.279	.283
83693	1	7	328	.143	.178	.198	.213	.224	.233	.245	.254	.262	.268	.274	.280	.284	.289
66371	2	7	292	.149	.184	.204	.219	.230	.239	.250	.260	.267	.274	.280	.285	.290	.295
52635	3	7	.260	.154	.189	.210	.224	.236	.245	.256	.265	.273	.280	.286	.291	.296	.301
41741	4	7	.232	.160	.195	.216	.230	.242	.251	.262	.271	.279	.286	.292	.297	.302	.306
33102	5	7	.206	.166	.201	.222	.236	.247	.257	.268	.277	.285	.292	.298	.303	.308	.312
26251	6	7	.184	.172	.207	.228	.242	.253	.263	.274	.283	.291	.298	.304	.309	.314	.318

		DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
2000000		.212	.219	230	239	.247	.254	.260	270	.278	.286	.292	.298	.303	.307	.312	.321	.329
1900000		.213	.220	.231	.241	.248	.255	.261	.271	.280	.287	293	.299	.304	.309	.313	.322	.330
1800000		.215	222	.233	242	.250	.257	263	273	.281	288	295	.300	.305	.310	.314	323	331
1700000		.216	.223	.234	.243	.251	.258	.264	.274	.283	.290	.296	.302	.307	.311	.316	.325	.333
1600000		.218	.225	.236	.245	.253	260	.266	.276	.284	.291	.298	.303	.308	.313	.317	.326	.334
1500000		.219	.226	.238	.247	.255	.261	.267	.277	286	293	.299	.305	.310	.315	.319	.328	.336
1400000		.221	.228	.239	.248	.256	.263	.269	.279	.288	.295	.301	.307	.312	.316	.321	.330	.338
1300000		.223	.230	.241	.250	.258	.265	.271	.281	.289	.297	.303	.309	.314	.318	.323	332	.340
1200000		.225	232	.243	.252	.260	.267	273	.283	.291	299	.305	.311	.316	.320	.325	.334	.342
1100000		.227	.234	.245	.255	.262	.269	.275	.285	.294	.301	307	.313	.318	.323	.327	.336	.344
1000000		.230	.237	.248	257	.265	.272	.278	.288	.296	.304	.310	.315	.321	.325	.329	339	.346
950000		.231	.238	249	.258	.266	.273	.279	.289	.298	305	.311	.317	.322	.326	.331	340	.348
900000		.233	.239	.251	.260	.268	.274	.280	.290	.299	.306	.313	.318	.323	.328	.332	.341	.349
850000		.234	.241	252	.261	269	.276	.282	.292	.300	.308	.314	.320	.325	.329	.333	.343	.350
800000		.236	.242	254	.263	.271	.277	.283	.293	.302	.309	.315	.321	.326	.331	.335	.344	.352
750000		.237	.244	.255	.264	.272	.279	.285	.295	.304	.311	.317	.323	.328	.332	.337	.346	.354
700000		.239	.246	.257	.266	.274	.281	.287	.297	.305	.313	.319	.324	.330	.334	.338	.348	.355
650000		.241	.248	.259	.268	.276	.283	.289	.299	.307	.314	.321	.326	.331	.336	.340	.349	357
600000		.243	.250	.261	.270	.278	.285	.291	.301	.310	.317	.323	.329	.334	.338	.343	.352	.360
550000		.245	.252	.263	.273	.280	.287	.293	.303	.312	.319	.325	.331	.336	.341	.345	.354	.362
500000		.248	.255	.266	.275	.283	.290	.296	.306	.314	.321	.328	.333	.338	.343	.347	.356	.364
450000		.250	.257	.269	.278	.286	.292	.298	.308	.317	324	.330	.336	.341	.346	.350	.359	.367
400000		.254	.261	.272	.282	.289	.296	.302	.312	.321	328	.334	.340	.345	.349	.354	.363	.371
350000		.258	.264	.276	.285	.293	.299	.305	.316	.324	.331	.338	.343	.348	.353	.357	.366	.374
300000		.262	.268	.280	.289	.297	.303	.309	.319	.328	.335	.341	.347	.352	.357	.361	.370	.378
250000		.266	.273	.284	.293	.301	.308	.314	.324	.333	.340	.346	.352	.357	.361	.366	.375	.383
211600	0000	.273	.280	.291	.300	.308	.315	.321	.331	.340	.347	.353	.359	.364	.368	.373	.382	.390
167806	000	.279	.286	.297	.306	.314	.321	.327	.337	.345	.353	.359	.365	.370	.374	.378	.388	.395
133077	00	.285	.292	.303	.312	.320	.327	.333	.343	.351	.358	.365	.370	.375	.380	.384	.394	.401
105535	0	.291	.297	.309	.318	.326	.333	.338	.349	.357	.364	.371	.376	.381	.386	.390	.399	.407
83693	1	.297	.303	.315	.324	.332	.338	.344	.354	.363	.370	.377	.382	.387	.392	.396	.405	.413
66371	2	.302	.309	.321	.330	.338	.344	.350	.360	.369	.376	.382	.388	.393	.398	.402	.411	.419
52635	3	.308	.315	.326	.336	.343	.350	.356	.366	.375	.382	.388	.394	.399	.404	.408	.417	.425
41741	4	.314	.321	.332	.341	.349	.356	.362	.372	.381	.388	.394	.400	.405	.409	.414	.423	431
33102	5	.320	.327	.338	.347	.355	.362	.368	.378	.386	.394	.400	.406	.411	.415	.419	.429	.436
26251	6	.326	.333	344	.353	.361	.368	.374	.384	.392	.399	406	.411	.417	.421	.425	.435	.442

The table values were derived from the equation $x = 2\pi f L$, in which x is the reactance in ohms, L is the inductance in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 25 cycles is f/25 times the table values.

The reactance x' at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D′/D	1·05	1·10	1·15	1·20	1·25	1·30	1·35	1·40	1·45	1·50	1·55	1·60	1·65	1·70	1·75	1·80	1·85	1·90	1·95	2·00
x +	002	·005	·007	·009	·011	·013	·015	·017	·019	·020	·022	·024	·025	027	·028	·030	·031	·032	·034	·035

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE X—25 CYCLE REACTANCE PER MILE OF SINGLE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

MULTIPLE LAYER CONDUCTORS—ALL CURRENT DENSITIES

25 CYCLE REACTANCE X IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES)

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S.) (ALUMINUM)	NUMBER OF WIRES ALUMINUM	NUMBER OF WIRES STEEL	COPPER EQUIVALENT CIRCULAR MILS OR A W G BASED UPON COPPER 97, ALUMIN. 61	2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET 1.07 M.	4 FEET 1.22 M.	5 FEET 1.52 M.	6 FEET 1.83 M.	7 FEET 2.13 M.	8 FEET 2.44 M.	9 FEET 2.74 M.	11 FEET 3.35 M.	13 FEET 3.96 M.	15 FEET 4.57 M.	17 FEET 5.18 M.	19 FEET 5.79 M.	21 FEET 6.40 M.	23 FEET 7.01 M.	25 FEET 7.62 M.	30 FEET 9.14 M.	35 FEET 10.67 M.
1 590 000	54	7	1 000 000	.177	.189	.198	.206	.212	.224	.233	.241	.247	.253	.264	.272	.279	.286	.291	.296	.301	.305	.314	.322
1 510 500	54	7	950 000	.178	.190	.199	.207	.213	.225	.234	.242	.248	.254	.265	.273	.280	.287	.292	.297	.302	.306	.315	.323
1 431 000	54	7	900 000	.180	.191	.200	.208	.215	.226	.235	.243	.250	.256	.266	.274	.282	.288	.294	.299	.303	.307	.317	.324
1 351 500	54	7	850 000	.181	.192	.201	.209	.216	.227	.236	.244	.251	.257	.267	.276	.283	.289	.295	.300	.304	.309	.318	.326
1 272 000	54	7	800 000	.182	.194	.203	.211	.217	.229	.238	.246	.253	.258	.269	.277	.284	.291	.296	.301	.306	.310	.319	.327
1 192 500	54	7	750 000	.184	.195	.204	.212	.219	.230	.239	.247	.254	.260	.270	.279	.286	.292	.298	.303	.307	.312	.321	.329
1 113 000	54	7	700 000	.185	.197	.206	.214	.220	.232	.241	.249	.256	.261	.272	.280	.287	.294	.299	.304	.309	.313	.322	.330
1 033 500	54	7	650 000	.187	.198	.208	.215	.222	.234	.243	.251	.257	.263	.273	.282	.289	.295	.301	.306	.311	.315	.324	.332
954 000	54	7	600 000	.189	.201	.210	.218	.224	.236	.245	.253	.259	.265	.275	.284	.291	.297	.303	.308	.313	.317	.326	.334
900 000	54	7	566 000	.191	.202	.211	.219	.226	.237	.246	.254	.261	.267	.277	.285	.292	.299	.305	.310	.314	.318	.327	.335
874 500	54	7	550 000	.191	.203	.212	.220	.226	.238	.247	.255	.261	.267	.277	.286	.293	.299	.305	.310	.315	.319	.328	.336
795 000	54	7	500 000	.194	.205	.214	.222	.229	.240	.249	.257	.264	.270	.280	.288	.296	.302	.307	.313	.317	.321	.331	.338
715 500	54	7	450 000	.196	.208	.217	.225	.231	.243	.252	.260	.266	.272	.283	.291	.298	.305	.310	.315	.320	.324	.333	.341
666 600	54	7	419 000	.198	.209	.219	.226	.233	.244	.254	.261	.268	.274	.284	.293	.300	.306	.312	.317	.322	.326	.335	.343
636 000	54	7	400 000	.199	.211	.220	.228	.234	.246	.255	.263	.269	.275	.286	.294	.301	.307	.313	.318	.323	.327	.336	.344
605 000	54	7	380 500	.201	.212	.221	.229	.236	.247	.256	.264	.271	.277	.287	.295	.302	.309	.314	.319	.324	.328	.338	.345
556 500	30	7	350 000	.201	.212	.221	.229	.236	.247	.256	.264	.271	.277	.287	.295	.302	.309	.314	.319	.324	.328	.338	.345
556 500	26	7	350 000	.203	.214	.223	.231	.238	.249	.258	.266	.273	.279	.289	.298	.305	.311	.317	.322	.326	.331	.340	.348
518 000	42	19	326 000	.198	.209	.219	.226	.233	.244	.254	.261	.268	.274	.284	.293	.300	.306	.312	.317	.322	.326	.335	.343
500 000	30	7	314 500	.203	.214	.224	.231	.238	.250	.259	.266	.273	.279	.289	.298	.305	.311	.317	.322	.327	.331	.340	.348
477 000	30	7	300 000	.204	.216	.225	.233	.239	.251	.260	.268	.275	.280	.291	.299	.306	.313	.318	.323	.328	.332	.341	.349
477 000	26	7	300 000	.207	.218	.227	.235	.242	.253	.262	.270	.277	.283	.293	.302	.309	.315	.321	.326	.330	.335	.344	.351
397 500	30	7	250 000	.209	.221	.230	.238	.244	.256	.265	.273	.280	.286	.296	.304	.311	.318	.323	.328	.333	.337	.346	.354
397 500	26	7	250 000	.212	.223	.232	.240	.247	.258	.267	.275	.282	.288	.298	.307	.314	.320	.326	.331	.335	.340	.349	.357
336 400	30	7	0000	.214	.225	.234	.242	.249	.260	.269	.277	.284	.290	.300	.309	.316	.322	.328	.333	.337	.342	.351	.359
336 400	26	7	0000	.216	.228	.237	.244	.251	.263	.272	.280	.286	.292	.302	.311	.318	.324	.330	.335	.340	.344	.353	.361
300 000	30	7	188 800	.217	.228	.238	.245	.252	.263	.273	.280	.287	.293	.303	.312	.319	.325	.331	.336	.340	.345	.354	.362
300 000	26	7	188 800	.220	.231	.240	.248	.255	.266	.275	.283	.290	.296	.306	.314	.321	.328	.333	.338	.343	.347	.357	.364
266 800	26	7	000	.222	.233	.242	.250	.257	.268	.277	.285	.292	.298	.308	.317	.324	.330	.336	.341	.345	.350	.359	.367

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 0 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G	ALUM-INUM	STEEL	COPPER EQUIVALENT	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	30	35
266 800	6	7	000	.229	.241	.250	.258	.264	.276	.285	.293	.299	.305	.316	.324	.331	.338	.343	.348	.353	.357	.366	.374
0000	6	1	00	.253	.265	.274	.282	.288	.300	.309	.317	.323	.329	.339	.348	.355	.362	.367	.372	.377	.381	.390	.398
000	6	1	0	.260	.271	.281	.288	.295	.306	.316	.323	.330	.336	.346	.355	.362	.368	.374	.379	.384	.388	.397	.405
00	6	1	1	.266	.277	.287	.294	.301	.312	.322	.329	.336	.342	.352	.361	.368	.374	.380	.385	.390	.394	.403	.411
0	6	1	2	.272	.283	.292	.300	.307	.318	.327	.335	.342	.348	.358	.366	.374	.380	.386	.391	.395	.399	.409	.416
1	6	1	3	.277	.288	.297	.305	.312	.323	.332	.340	.347	.353	.363	.372	.379	.385	.391	.396	.400	.405	.414	.422
2	6	1	4	.282	.293	.302	.310	.317	.328	.338	.345	.352	.358	.368	.377	.384	.390	.396	.401	.405	.410	.419	.427
3	6	1	5	.287	.298	.307	.315	.322	.333	.343	.350	.357	.363	.373	.382	.389	.395	.401	.406	.410	.415	.424	.432
4	6	1	6	.292	.304	.313	.321	.327	.339	.348	.356	.362	.368	.379	.387	.394	.400	.406	.411	.416	.420	.429	.437
5	6	1	7	.297	.309	.318	.326	.332	.344	.353	.361	.368	.373	.384	.392	.399	.406	.411	.416	.421	.425	.434	.442
6	6	1	8	.303	.314	.324	.331	.338	.349	.359	.366	.373	.379	.389	.398	.405	.411	.417	.422	.427	.431	.440	.448

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 600 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G	ALUM-INUM	STEEL	COPPER EQUIVALENT	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	30	35
266 800	6	7	000	.237	.248	.257	.265	.272	.283	.292	.300	.307	.313	.323	.332	.339	.345	.351	.356	.360	.365	.374	.381
0000	6	1	00	.262	.273	.282	.290	.297	.308	.317	.325	.332	.338	.348	.356	.364	.370	.376	.381	.385	.389	.399	.406
000	6	1	0	.266	.277	.286	.294	.301	.312	.321	.329	.336	.342	.352	.361	.368	.374	.380	.385	.389	.394	.403	.411
00	6	1	1	.270	.282	.291	.299	.305	.317	.326	.334	.340	.346	.357	.365	.372	.379	.384	.389	.394	.398	.407	.415
0	6	1	2	.275	.286	.295	.303	.310	.321	.330	.338	.345	.351	.361	.369	.377	.383	.389	.394	.398	.402	.412	.419
1	6	1	3	.279	.291	.300	.308	.314	.326	.335	.343	.349	.355	.366	.374	.381	.388	.393	.398	.403	.407	.416	.424
2	6	1	4	.284	.295	.304	.312	.319	.330	.339	.347	.354	.360	.370	.379	.386	.392	.398	.403	.407	.411	.421	.428
3	6	1	5	.288	.299	.309	.316	.323	.335	.344	.351	.358	.364	.374	.383	.390	.396	.402	.407	.412	.416	.425	.433
4	6	1	6	.293	.304	.313	.321	.328	.339	.348	.356	.363	.369	.379	.387	.395	.401	.407	.412	.416	.420	.430	.437
5	6	1	7	.298	.310	.319	.327	.333	.345	.354	.362	.368	.374	.384	.393	.400	.406	.412	.417	.422	.426	.435	.443
6	6	1	8	.304	.316	.325	.332	.339	.351	.360	.368	.374	.380	.390	.399	.406	.412	.418	.423	.428	.432	.441	.449

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 1200 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G	ALUM-INUM	STEEL	COPPER EQUIVALENT	2	2.5	3	3.5	4	5	6	7	8	9	11	13	15	17	19	21	23	25	30	35
266 800	6	7	000	.270	.281	.291	.298	.305	.316	.326	.333	.340	.346	.356	.365	.372	.378	.384	.389	.393	.398	.407	.415
0000	6	1	00	.273	.284	.294	.301	.308	.319	.329	.336	.343	.349	.359	.368	.375	.381	.387	.392	.397	.401	.410	.418
000	6	1	0	.278	.290	.299	.307	.313	.325	.334	.342	.348	.354	.365	.373	.380	.387	.392	.397	.402	.406	.415	.423
00	6	1	1	.282	.294	.303	.311	.317	.329	.338	.346	.352	.358	.369	.377	.384	.391	.396	.401	.406	.410	.419	.427
0	6	1	2	.285	.296	.306	.313	.320	.332	.341	.348	.355	.361	.371	.380	.387	.393	.399	.404	.409	.413	.422	.430
1	6	1	3	.288	.299	.308	.314	.323	.334	.343	.351	.358	.364	.374	.382	.390	.396	.402	.407	.411	.415	.425	.432
2	6	1	4	.290	.301	.310	.316	.325	.336	.345	.353	.360	.366	.376	.384	.392	.398	.403	.409	.413	.417	.427	.434
3	6	1	5	.292	.303	.312	.320	.327	.338	.347	.355	.362	.368	.378	.386	.394	.400	.406	.411	.415	.419	.429	.436
4	6	1	6	.294	.305	.315	.322	.329	.340	.350	.357	.364	.370	.380	.389	.396	.402	.408	.413	.418	.422	.431	.439
5	6	1	7	.301	.312	.321	.329	.336	.347	.357	.364	.371	.377	.387	.396	.403	.409	.415	.420	.424	.429	.438	.446
6	6	1	8	.306	.318	.327	.335	.341	.353	.362	.370	.376	.382	.393	.401	.408	.415	.420	.425	.430	.434	.443	.451

By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The table values were derived from the equation $x = 2\pi f L_1$ in which x is the reactance in ohms, L is the inductance in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 25 cycles is f/25 times the table values.

The reactance x' at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms, to be added to that at the next smaller spacing may be taken from table below.

D′/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
x +	.002	.005	.007	.009	.011	.013	.015	.017	.019	.020	.022	.024	.025	.027	.028	.030	.031	.032	.034	.035

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XI—60 CYCLE REACTANCE PER MILE OF SINGLE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE.

SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	60 CYCLE REACTANCE X IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.) DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE (B&S)			2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
2000000		127	1.631	.140	.224	.273	.308	.335	.357	.384	.406	.425	.441	.455	.468	.480	.490
1900000		127	1.590	.143	.227	.276	.311	.338	.360	.387	.409	.428	.444	.459	.471	.483	.494
1800000		127	1.548	.146	.230	.279	.314	.341	.363	.391	.413	.431	.448	.462	.475	.486	.497
1700000		127	1.504	.150	.234	.283	.318	.345	.367	.394	.416	.435	.451	.465	.478	.490	.500
1600000		127	1.459	.153	.237	.287	.321	.349	.371	.398	.420	.439	.455	.469	.482	.493	.504
1500000		91	1.412	.157	.241	.291	.326	.353	.375	.402	.424	.443	.459	.473	.486	.498	.508
1400000		91	1.364	.162	.246	.295	.330	.357	.379	.406	.428	.447	.463	.477	.490	.502	.512
1300000		91	1.315	.166	.250	.299	.334	.361	.383	.411	.433	.451	.468	.482	.495	.506	.517
1200000		91	1.263	.171	.255	.304	.339	.366	.388	.415	.438	.456	.472	.487	.500	.511	.522
1100000		91	1.209	.176	.260	.309	.344	.371	.394	.421	.443	.461	.478	.492	.505	.516	.527
1000000		61	1.152	.182	.267	.316	.351	.378	.400	.427	.449	.468	.484	.498	.511	.523	.533
950000		61	1.123	.186	.270	.319	.354	.381	.403	.430	.452	.471	.487	.501	.514	.526	.536
900000		61	1.093	.189	.273	.322	.357	.384	.406	.433	.455	.474	.490	.505	.517	.529	.540
850000		61	1.062	.192	.276	.326	.360	.388	.410	.437	.459	.478	.494	.508	.521	.532	.543
800000		61	1.031	.196	.280	.329	.364	.391	.413	.440	.463	.481	.497	.512	.525	.536	.547
750000		61	.998	.200	.284	.333	.368	.395	.417	.444	.466	.485	.501	.516	.528	.540	.551
700000		61	.964	.204	.288	.337	.372	.399	.421	.449	.471	.489	.506	.520	.533	.544	.555
650000		61	.929	.209	.293	.342	.377	.404	.426	.453	.475	.494	.510	.524	.537	.549	.559
600000		37	.891	.214	.298	.348	.382	.410	.432	.459	.481	.500	.516	.530	.543	.554	.565
550000		37	.853	.220	.304	.353	.388	.415	.437	.464	.486	.505	.521	.535	.548	.560	.570
500000		37	.814	.225	.309	.359	.394	.421	.443	.470	.492	.511	.527	.541	.554	.565	.576
450000		37	.772	.232	.316	.365	.400	.427	.449	.476	.498	.517	.533	.548	.560	.572	.582
400000		19	.725	.241	.325	.374	.409	.436	.458	.485	.507	.526	.542	.557	.569	.581	.592
350000		19	.679	.249	.333	.382	.417	.444	.466	.493	.516	.534	.550	.565	.578	.589	.600
300000		19	.628	.258	.342	.392	.426	.454	.476	.503	.525	.544	.560	.574	.587	.598	.609
250000		19	.574	.269	.353	.403	.438	.465	.487	.514	.536	.555	.571	.585	.598	.610	.620
211600	0000	7	.522	.286	.370	.419	.454	.481	.504	.531	.553	.571	.588	.602	.615	.626	.637
167806	000	7	.464	.300	.384	.434	.468	.495	.518	.545	.567	.586	.602	.616	.629	.640	.651
133077	00	7	.414	.314	.398	.448	.482	.510	.532	.559	.581	.600	.616	.630	.643	.654	.665
105535	0	7	.368	.328	.412	.462	.497	.524	.546	.573	.595	.614	.630	.644	.657	.668	.679
83693	1	7	.328	.342	.427	.476	.511	538	.560	.587	.609	.628	.644	.658	.671	.683	.693
66371	2	7	.292	.356	.441	.490	.525	552	.574	.601	.623	.642	.658	.672	.685	.697	.707
52635	3	7	.260	.371	.455	.504	.539	566	.588	.615	.637	.656	.672	.686	.699	.711	.721
41741	4	7	.232	.385	.469	.518	.553	.580	.602	.629	.651	.670	.686	.700	.713	.725	.735
33102	5	7	.206	.399	.483	.532	.567	.594	.616	.643	.665	.684	.700	.714	.727	.739	.749
26251	6	7	.184	.413	.497	.546	.581	.608	.630	.657	.679	.698	.714	.729	.741	.753	.763

		DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
2000000		.509	.525	.552	.574	.593	.609	.624	.648	.668	.686	.701	.714	.727	.738	.748	.770	.788
1900000		.512	.528	.555	.578	.596	.613	.627	.651	.671	.689	.704	.717	.730	.741	.751	.773	.792
1800000		.515	.532	.559	.581	.600	.616	.630	.654	.675	.692	.707	.721	.733	.744	.754	.776	.795
1700000		.519	.535	.562	.584	.603	.619	.634	.658	.678	.696	.711	.724	.736	.747	.758	.780	.798
1600000		.523	.539	.566	.588	.607	.623	.637	.662	.682	.699	.714	.728	.740	.751	.761	.783	.802
1500000		.527	.543	.570	.592	.611	.627	.641	.666	.686	.703	.719	.732	.744	.755	.765	.787	.806
1400000		.531	.547	.574	.596	.615	.631	.646	.670	.690	.708	.723	.736	.748	.759	.770	.792	.810
1300000		.535	.552	.579	.601	.620	.636	.650	.674	.695	.712	.727	.741	.753	.764	.774	.796	.815
1200000		.540	.557	.584	.606	.624	.641	.655	.679	.700	.717	.732	.746	.758	.769	.779	.801	.820
1100000		.546	.562	.589	.611	.630	.646	.660	.685	.705	.722	.737	.751	.763	.774	.784	.806	.825
1000000		.552	.568	.595	.617	.636	.652	.666	.691	.711	.728	.744	.757	.769	.780	.790	.813	.831
950000		.555	.571	.598	.620	.639	.655	.670	.694	.714	.732	.747	.760	.772	.783	.794	.816	.834
900000		.558	.574	.601	.624	.642	.659	.673	.697	.717	.735	.750	.763	.776	.787	.797	.819	.838
850000		.562	.578	.605	.627	.646	.662	.676	.701	.721	.738	.753	.767	.779	.790	.800	.822	.841
800000		.565	.582	.609	.631	.649	.666	.680	.704	.725	.742	.757	.771	.783	.794	.804	.826	.845
750000		.569	.585	.613	.635	.653	.670	.684	.708	.729	.746	.761	.775	.787	.798	.808	.830	.849
700000		.573	.590	.617	.639	.658	.674	.688	.712	.733	.750	.765	.779	.791	.802	.812	.834	.853
650000		.578	.594	.621	.643	.662	.678	.693	.717	.737	.755	.770	.783	.795	.806	.817	.839	.857
600000		.584	.600	.627	.649	.668	.684	.698	.723	.743	.760	.775	.789	.801	.812	.822	.844	.863
550000		.589	.605	.632	.654	.673	.689	.704	.728	.748	.766	.781	.794	.806	.817	.828	.850	.868
500000		.595	.611	.638	.660	.679	.695	.709	.734	.754	.771	.786	.800	.812	.823	.833	.855	.874
450000		.601	.617	.644	.667	.685	.701	.716	.740	.760	.778	.793	.806	.819	.830	.840	.862	.881
400000		.610	.626	.654	.676	.694	.711	.725	.749	.769	.787	.802	.816	.828	.839	.849	.871	.890
350000		.618	.635	.662	.684	.702	.719	.733	.757	.778	.795	.810	.824	.836	.847	.857	.879	.898
300000		.628	.644	.671	.693	.712	.728	.742	.767	.787	.804	.819	.833	.845	.856	.866	.888	.907
250000		.639	.655	.682	.704	.723	.739	.753	.778	.798	.815	.831	.844	.856	.867	.877	.899	.918
211600	0000	.656	.672	.699	.721	.740	.756	.770	.795	.815	.832	.847	.861	.873	.884	.894	.916	.935
167806	000	.670	.686	.713	.735	.754	.770	.784	.809	.829	.846	.861	.875	.887	.898	.908	.930	.949
133077	00	.684	.700	.727	.749	.768	.784	.798	.823	.843	.860	.875	.889	.901	.912	.922	.944	.963
105535	0	.698	.714	.741	.763	.782	.798	.812	.837	.857	.874	.890	.903	.915	.926	.936	.958	.977
83693	1	.712	.728	.755	.777	.796	.812	.826	.851	.871	.888	.904	.917	.929	.940	.950	.973	.991
66371	2	.726	.742	.769	.791	.810	.826	.841	.865	.885	.902	.918	.931	.943	.954	.964	.987	1.005
52635	3	.740	.756	.783	.805	.824	.840	.855	.879	.899	.917	.932	.945	.957	.968	.979	1.001	1.019
41741	4	.754	.770	.797	.819	.838	.854	.869	.893	.913	.931	.946	.959	.971	.982	.993	1.015	1.033
33102	5	.768	.784	.811	.833	.852	.868	.883	.907	.927	.945	.960	.973	.986	.997	1.007	1.029	1.048
26251	6	.782	.798	.825	.848	.866	.882	.897	.921	.941	.959	.974	.987	1.000	1.011	1.021	1.043	1.062

The table values were derived from the equation $x = 2\pi f L$, in which x is the reactance in ohms, L is the inductance in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 60 cycles is f/60 times the table values.

The reactance x at any spacing D′ not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D′/D	1·05	1·10	1·15	1·20	1·25	1·30	1·35	1·40	1·45	1·50	1·55	1·60	1·65	1·70	1·75	1·80	1·85	1·90	1·95	2·00
x +	·006	·012	·017	·022	·027	·032	·036	·041	·045	·049	·053	·057	·061	·064	·068	·071	·075	·078	·081	·084

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XII—60 CYCLE REACTANCE PER MILE OF SINGLE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

MULTIPLE LAYER CONDUCTORS—ALL CURRENT DENSITIES

60 CYCLE REACTANCE x IN OHMS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.) — DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S) (ALUMINUM)	NUMBER OF WIRES ALUMINUM	NUMBER OF WIRES STEEL	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M.)	23 FEET (7.01 M.)	25 FEET (7.62 M.)	30 FEET (9.14 M.)	35 FEET (10.67 M.)
1 590 000	54	7	1 000 000	.426	.452	.475	.494	.510	.537	.559	.578	.594	.608	.632	.653	.670	.685	.699	.711	.722	.732	.754	.773
1 510 500	54	7	950 000	.428	.455	.477	.496	.512	.539	.561	.580	.596	.610	.635	.655	.673	.688	.701	.713	.724	.734	.757	.775
1 431 000	54	7	900 000	.431	.458	.480	.499	.515	.542	.564	.583	.599	.613	.638	.658	.676	.691	704	.716	727	.737	.760	.778
1 351 500	54	7	850 000	.434	.461	.483	.502	.518	.545	.567	.586	.602	.616	.641	.661	.679	.694	.707	.719	.730	.740	.763	782
1 272 000	54	7	800 000	.438	.465	.487	.506	.522	.549	.571	.590	.606	.620	.644	.665	.682	.698	.711	.723	.734	.744	.766	.785
1 192 500	54	7	750 000	.441	.469	.491	.509	.526	.553	.575	.593	.610	.624	648	.668	.686	.701	.714	.727	.738	.748	770	.789
1 113 000	54	7	700 000	.445	.472	.494	.513	.529	.556	.578	.597	.613	.627	.652	.672	.690	.705	.718	.730	.741	751	.774	.793
1 033 500	54	7	650 000	.449	.476	.498	.517	.533	.560	.583	.601	.618	.632	.656	.676	.694	.709	.722	.734	.745	.756	.778	797
954 000	54	7	600 000	.454	.481	.503	.522	.538	.565	.587	.606	.622	.637	.661	.681	.699	.714	727	739	751	760	.783	.802
900 000	54	7	566 000	.457	.484	.506	.525	.541	.569	.590	.609	.625	.640	.664	.684	.702	.717	.731	.743	.754	.764	.786	.805
874 500	54	7	550 000	.459	.486	.508	.527	.543	.570	.592	.611	.627	.641	.666	.686	.703	.719	.732	.744	.755	.765	.788	.806
795 000	54	7	500 000	.465	.492	.514	.532	.549	.576	.598	.616	.633	.647	.671	692	.709	724	.738	750	761	.771	.793	.812
715 500	54	7	450 000	.471	.498	.520	.539	.555	.582	.604	.623	.639	.653	.678	.698	.716	.731	.744	.756	.767	777	.800	.818
666 600	54	7	419 000	.475	.503	.525	.543	.560	.587	.609	.627	.644	.658	.682	.703	.720	.735	.749	.761	.772	782	.804	.823
636 000	54	7	400 000	.478	.505	.527	.546	.562	.589	.612	.630	.646	.661	.685	.705	723	.738	.751	.763	.774	785	.807	.825
605 000	54	7	380 500	.481	.508	.530	.549	.565	.592	.615	.633	.649	.664	.688	.708	726	.741	.754	.766	.777	.788	.810	.828
556 500	30	7	350 000	.481	.508	.530	.549	.565	.592	.615	.633	.649	.664	.688	.708	.726	.741	.754	.766	.777	.788	.810	.828
556 500	26	7	350 000	.487	.514	.536	.555	.571	.598	.620	.639	.655	.669	.694	714	.731	.747	.760	.772	783	.793	.816	.834
518 000	42	19	326 000	.475	.503	.525	.543	.560	.587	.609	.627	.644	.658	.682	703	720	.735	.749	.761	.772	.782	.804	.823
500 000	30	7	314 500	.488	.515	.537	.555	.572	.599	.621	.639	.656	.670	.694	.715	.732	.747	761	.773	.784	794	.816	.835
477 000	30	7	300 000	.491	.518	.540	.558	.575	.602	.624	.642	.659	.673	698	.718	735	.750	.764	776	.787	797	819	.838
477 000	26	7	300 000	.496	.523	.546	.564	.580	.607	.630	.648	.664	.679	.703	.724	.741	.756	.770	.782	793	803	875	.843
397 500	30	7	250 000	.503	.530	.552	.570	.587	.614	.636	.655	.671	.685	.710	.730	.747	.762	.776	.788	.799	.809	.831	.850
397 500	26	7	250 000	.508	.535	.558	.576	.592	.619	.642	.660	.676	.691	.715	736	753	.768	.782	.794	.805	815	.837	855
336 400	30	7	0 000	.513	.540	.563	.581	.597	.624	.647	.665	.681	.696	.720	.740	.758	.773	.786	.799	.809	.820	.842	860
336 400	26	7	0 000	.519	.546	.568	.587	.603	.630	.652	.671	.687	.701	.726	.746	.763	.779	.792	.804	.815	.825	.848	.866
300 000	30	7	188 800	.521	.548	.570	.589	.605	.632	.654	.673	.689	.703	.728	.748	.765	.780	.794	.806	.817	.827	.849	.868
300 000	26	7	188 800	.527	.554	.576	.595	.611	.638	.660	.679	.695	.709	.734	.754	.771	.786	.800	.812	.823	.833	.855	.874
266 800	26	7	000	.532	.560	.582	.600	.616	.644	.666	.684	.701	.715	.739	.760	.777	.792	.806	.818	.829	.839	.861	.880

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 0 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUMINUM	STEEL	COPPER EQUIVALENT	2 FT	2.5 FT	3 FT	3.5 FT	4 FT	5 FT	6 FT	7 FT	8 FT	9 FT	11 FT	13 FT	15 FT	17 FT	19 FT	21 FT	23 FT	25 FT	30 FT	35 FT
266 800	6	7	000	.550	.578	.600	.618	.635	.662	.684	.702	.719	.733	.757	.778	.795	.810	.824	.836	.847	.857	.879	.898
0 000	6	1	00	.608	.635	.657	.676	.692	.719	.741	.760	.776	.790	.815	.835	.852	.868	.881	.893	.904	.914	.937	.955
000	6	1	0	.624	.651	.673	.692	.708	.735	.757	.776	.792	.806	.831	.851	.869	.884	897	.909	.920	.930	.953	.971
00	6	1	1	.638	.665	.688	.706	.722	.750	.772	.790	.806	.821	.845	.866	.883	.898	.912	.924	.935	.945	.967	.986
0	6	1	2	.652	.679	.701	.720	.736	.763	.785	.804	.820	.834	.859	.879	.897	.912	.925	.937	.948	.958	.981	.999
1	6	1	3	.664	.691	.714	.732	.748	.776	.798	.816	.832	.847	.871	.892	.909	.924	.938	.950	.961	.971	.993	1.01
2	6	1	4	.676	.704	.726	.744	.760	.788	.810	.828	.845	.859	.883	.904	.921	.936	.950	.962	.973	.983	1.01	1.02
3	6	1	5	.688	.716	.738	.756	.773	.800	.822	.840	.857	.871	.895	.916	.933	.948	.962	.974	.985	.995	1.02	1.04
4	6	1	6	.701	.728	.751	.769	.785	.812	.835	.853	.869	.884	.908	.929	.946	.961	.975	.987	.998	1.01	1.03	1.05
5	6	1	7	.714	.741	.763	.782	.798	.825	.847	.866	.882	.896	.921	.941	.958	.973	.987	.999	1.01	1.02	1.04	1.06
6	6	1	8	.727	.754	.777	.795	.811	.838	.861	.879	.895	.910	.934	.955	.972	.987	1.00	1.01	1.02	1.03	1.06	1.07

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 600 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUMINUM	STEEL	COPPER EQUIVALENT	2 FT	2.5 FT	3 FT	3.5 FT	4 FT	5 FT	6 FT	7 FT	8 FT	9 FT	11 FT	13 FT	15 FT	17 FT	19 FT	21 FT	23 FT	25 FT	30 FT	35 FT
266 800	6	7	000	.568	.595	.618	.636	.652	.679	.702	.720	.736	.751	.775	.796	.813	.828	.842	.854	.865	.875	.897	.915
0 000	6	1	00	.628	.655	.677	.696	.712	.739	.761	.780	.796	.810	.835	.855	.872	.888	.901	.913	.924	.934	.956	.975
000	6	1	0	.638	.665	.687	.706	.722	.749	.771	.790	.806	820	.845	.865	.883	.898	.911	.923	.934	.944	.967	.985
00	6	1	1	.648	.676	.698	.716	.733	.760	.782	.800	.817	.831	.855	.876	.893	.908	.922	.934	.945	.955	.977	.996
0	6	1	2	.659	.686	.708	.727	.743	.770	.793	.811	.827	.842	.866	.886	.904	.919	.932	.944	.955	.966	.988	1.01
1	6	1	3	.670	.698	.720	.738	.754	.782	.804	.822	.838	.853	.877	.898	.915	.930	.944	.956	.967	.977	.999	1.02
2	6	1	4	.681	.708	.730	.749	.765	.792	.814	.833	.849	.863	.888	.908	.926	.941	.954	.966	.977	.987	1.01	1.03
3	6	1	5	.691	.719	.741	.759	.776	.803	.825	.843	.860	.874	.898	.919	.936	.951	.965	.977	.988	.998	1.02	1.04
4	6	1	6	.702	.730	.752	.770	.786	.814	.836	.854	.871	.885	.909	.930	.947	.962	.976	.988	.999	1.01	1.03	1.05
5	6	1	7	.716	.743	.765	.783	.800	.827	.849	.868	.884	.898	.923	.943	.960	.975	.989	1.00	1.01	1.02	1.04	1.06
6	6	1	8	.730	.757	.779	.798	.814	.841	.863	.882	.898	.912	.937	.957	.975	.990	1.00	1.02	1.03	1.04	1.06	1.08

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 1200 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUMINUM	STEEL	COPPER EQUIVALENT	2 FT	2.5 FT	3 FT	3.5 FT	4 FT	5 FT	6 FT	7 FT	8 FT	9 FT	11 FT	13 FT	15 FT	17 FT	19 FT	21 FT	23 FT	25 FT	30 FT	35 FT
266 800	6	7	000	.648	.675	.697	.716	.732	.759	.781	.800	.816	.830	.855	.875	.892	.907	.921	.933	.944	.954	.976	.995
0 000	6	1	00	.655	.682	.705	.723	.739	.766	.789	.807	.823	.838	.862	.883	.900	.915	.929	.941	.952	.962	.984	1.00
000	6	1	0	.668	.695	.717	.736	.752	.779	.802	.820	.836	.851	.875	.895	.913	.928	.941	.953	.964	.975	.997	1.02
00	6	1	1	.677	.705	.727	.745	.762	.789	.811	.829	.846	.860	.884	.905	.922	.937	.951	.963	.974	.984	1.01	1.03
0	6	1	2	.684	.711	.734	.752	.768	.796	.818	.836	.852	.867	.891	.912	.929	.944	.958	.970	.981	.991	1.01	1.03
1	6	1	3	.690	.717	.740	.754	.774	.802	.824	.842	.858	.873	.897	.918	.935	.950	.964	.976	.987	.997	1.02	1.04
2	6	1	4	.695	.722	.744	.758	.779	.806	.828	.847	.863	.877	.902	.922	.940	.955	.968	.980	.991	1.00	1.02	1.04
3	6	1	5	.700	.727	.749	.768	.784	.811	.833	.852	.868	.882	.907	.927	.944	.960	.973	.985	.996	1.01	1.03	1.05
4	6	1	6	.706	.733	.755	.774	.790	.817	.839	.858	.874	.888	.913	.933	.950	.966	.979	.991	1.00	1.01	1.03	1.05
5	6	1	7	.722	.749	.771	.790	.806	.833	.855	.874	.890	.904	.929	.949	.967	.982	.995	1.01	1.02	1.03	1.05	1.07
6	6	1	8	.735	.762	.785	.803	.819	.846	.869	.887	.903	.918	.942	.963	.980	.995	1.01	1.02	1.03	1.04	1.06	1.08

By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The table values were derived from the equation $x = 2\pi f L$, in which x is the reactance in ohms, L is the inductance in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 60 cycles is f/60 times the table values.

The reactance x' at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms, to be added to that at the next smaller spacing may be taken from table below.

D′/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
x +	.006	.012	.017	.022	.027	.032	.036	.041	.045	.049	.053	.057	.061	.064	.068	.071	.075	.078	.081	.084

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

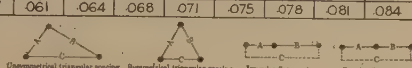


TABLE XIII—RATIO OF 25 CYCLE REACTANCE TO 25 CYCLE RESISTANCE AT 25°C—(77°F)

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

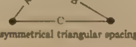
SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	RATIO OF 25 CYCLE REACTANCE TO 25 CYCLE RESISTANCE AT 25°C													
				DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S			2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
2000000		127	1.631	1.87	3.00	3.66	4.13	4.50	4.79	5.16	5.45	5.70	5.92	6.11	6.28	6.44	6.58
1900000		127	1.590	1.83	2.91	3.54	3.99	4.33	4.62	4.96	5.25	5.49	5.70	5.88	6.04	6.19	6.33
1800000		127	1.548	1.78	2.81	3.41	3.84	4.17	4.44	4.77	5.04	5.27	5.46	5.64	5.79	5.94	6.06
1700000		127	1.504	1.73	2.71	3.28	3.68	4.00	4.25	4.57	4.82	5.04	5.23	5.39	5.54	5.67	5.80
1600000		127	1.459	1.68	2.60	3.14	3.52	3.82	4.06	4.36	4.60	4.80	4.98	5.14	5.28	5.41	5.52
1500000		91	1.412	1.62	2.49	3.00	3.36	3.64	3.87	4.15	4.38	4.57	4.74	4.88	5.01	5.13	5.24
1400000		91	1.364	1.56	2.38	2.85	3.19	3.45	3.67	3.93	4.14	4.32	4.48	4.62	4.74	4.85	4.96
1300000		91	1.315	1.50	2.26	2.70	3.01	3.26	3.46	3.70	3.90	4.07	4.22	4.35	4.46	4.57	4.66
1200000		91	1.263	1.43	2.13	2.54	2.83	3.06	3.25	3.47	3.66	3.81	3.95	4.07	4.17	4.27	4.36
1100000		91	1.209	1.35	2.00	2.38	2.65	2.86	3.03	3.23	3.40	3.55	3.67	3.78	3.88	3.97	4.05
1000000		61	1.152	1.28	1.87	2.21	2.46	2.65	2.80	2.99	3.15	3.28	3.39	3.49	3.58	3.66	3.74
950000		61	1.123	1.24	1.80	2.13	2.36	2.54	2.69	2.87	3.02	3.14	3.25	3.34	3.43	3.51	3.58
900000		61	1.093	1.20	1.73	2.04	2.26	2.43	2.57	2.74	2.88	3.00	3.10	3.19	3.27	3.35	3.41
850000		61	1.062	1.15	1.65	1.95	2.16	2.32	2.45	2.62	2.75	2.86	2.96	3.04	3.12	3.19	3.25
800000		61	1.031	1.11	1.58	1.86	2.05	2.21	2.33	2.48	2.61	2.71	2.81	2.89	2.96	3.02	3.08
750000		61	.998	1.06	1.50	1.76	1.95	2.09	2.21	2.35	2.47	2.57	2.65	2.73	2.80	2.86	2.92
700000		61	.964	1.01	1.43	1.67	1.84	1.98	2.09	2.22	2.33	2.42	2.50	2.57	2.64	2.69	2.74
650000		61	.929	.959	1.35	1.57	1.73	1.86	1.96	2.08	2.19	2.27	2.35	2.41	2.47	2.52	2.57
600000		37	.891	.910	1.27	1.48	1.63	1.74	1.83	1.95	2.04	2.12	2.19	2.25	2.31	2.36	2.40
550000		37	.853	.856	1.18	1.38	1.51	1.62	1.70	1.81	1.90	1.97	2.03	2.09	2.14	2.18	2.22
500000		37	.814	.799	1.10	1.27	1.40	1.49	1.57	1.67	1.75	1.81	1.87	1.92	1.97	2.01	2.04
450000		37	.772	.740	1.01	1.17	1.28	1.36	1.44	1.52	1.59	1.65	1.70	1.75	1.79	1.83	1.86
400000		19	.725	.684	.923	1.06	1.16	1.24	1.30	1.38	1.44	1.50	1.54	1.58	1.62	1.65	1.68
350000		19	.679	.619	.829	.951	1.04	1.11	1.16	1.23	1.28	1.33	1.37	1.41	1.44	1.47	1.49
300000		19	.628	.551	.731	.836	.910	.968	1.02	1.07	1.12	1.16	1.19	1.23	1.25	1.28	1.30
250000		19	.574	.479	.629	.716	.778	.827	.866	.914	.953	.987	1.02	1.04	1.06	1.08	1.10
211600	0000	7	.522	.431	.558	.632	.684	.725	.758	.799	.833	.861	.885	.907	.926	.943	.959
167806	000	7	.464	.359	.459	.518	.560	.592	.618	.651	.677	.700	.719	.736	.751	.765	.778
133077	00	7	.414	.298	.378	.424	.457	.483	.504	.529	.550	.568	.584	.597	.609	.620	.630
105535	0	7	.368	.247	.310	.347	.373	.394	.410	.431	.447	.461	.473	.484	.494	.502	.510
83693	1	7	.328	.204	.254	.284	.304	.321	.334	.350	.363	.374	.384	.392	.400	.407	.413
66371	2	7	.292	.169	.208	.232	.248	.261	.271	.284	.295	.303	.311	.318	.324	.329	.334
52635	3	7	.260	.139	.170	.189	.202	.212	.220	.231	.239	.246	.252	.257	.262	266	.270
41741	4	7	.232	.114	.139	.154	.164	.172	.179	.187	.194	.199	.204	.208	.212	.215	.219
33102	5	7	.206	.094	.114	.125	.134	.140	.145	.152	.157	.161	.165	.168	.171	.174	.177
26251	6	7	.184	.077	.093	.102	.109	.114	.118	.123	.127	.131	.134	.136	.139	.141	.143

CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
2000000		6.83	7.05	7.41	7.71	7.96	8.18	8.37	8.70	8.97	9.20	9.41	9.59	9.75	9.90	10.0	10.3	10.6
1900000		6.57	6.77	7.12	7.40	7.64	7.85	8.04	8.35	8.61	8.83	9.02	9.20	9.35	9.49	9.62	9.91	10.2
1800000		6.29	6.49	6.82	7.09	7.32	7.52	7.69	7.99	8.24	8.45	8.63	8.80	8.95	9.08	9.20	9.47	9.70
1700000		6.01	6.20	6.51	6.77	6.99	7.18	7.34	7.62	7.86	8.06	8.23	8.39	8.53	8.66	8.78	9.03	9.25
1600000		5.73	5.90	6.20	6.44	6.65	6.83	6.98	7.25	7.47	7.66	7.83	7.97	8.11	8.23	8.34	8.58	8.79
1500000		5.44	5.60	5.88	6.11	6.30	6.47	6.62	6.87	7.08	7.26	7.42	7.55	7.68	7.79	7.90	8.13	8.32
1400000		5.14	5.29	5.56	5.77	5.95	6.11	6.25	6.48	6.68	6.84	6.99	7.12	7.24	7.35	7.44	7.66	7.84
1300000		4.83	4.98	5.22	5.42	5.59	5.73	5.86	6.08	6.26	6.42	6.56	6.68	6.79	6.89	6.98	7.18	7.35
1200000		4.52	4.65	4.88	5.06	5.22	5.35	5.47	5.68	5.85	5.99	6.12	6.23	6.33	6.42	6.51	6.69	6.85
1100000		4.19	4.32	4.53	4.70	4.84	4.97	5.08	5.26	5.42	5.55	5.67	5.77	5.87	5.95	6.03	6.20	6.34
1000000		3.87	3.98	4.17	4.33	4.46	4.57	4.67	4.84	4.99	5.11	5.21	5.31	5.39	5.47	5.54	5.70	5.83
950000		3.70	3.81	3.99	4.14	4.26	4.37	4.47	4.63	4.76	4.88	4.98	5.07	5.15	5.23	5.29	5.44	5.57
900000		3.53	3.64	3.81	3.95	4.07	4.17	4.26	4.41	4.54	4.65	4.75	4.83	4.91	4.98	5.04	5.18	5.30
850000		3.36	3.46	3.62	3.75	3.87	3.96	4.05	4.19	4.32	4.42	4.51	4.59	4.66	4.73	4.79	4.92	5.04
800000		3.19	3.28	3.43	3.56	3.66	3.75	3.84	3.97	4.09	4.19	4.27	4.35	4.42	4.48	4.53	4.66	4.77
750000		3.01	3.10	3.24	3.36	3.46	3.55	3.62	3.75	3.86	3.95	4.03	4.10	4.17	4.22	4.28	4.39	4.49
700000		2.84	2.92	3.05	3.16	3.25	3.33	3.40	3.52	3.63	3.71	3.79	3.85	3.91	3.97	4.02	4.13	4.22
650000		2.66	2.73	2.86	2.96	3.05	3.12	3.19	3.30	3.39	3.47	3.54	3.60	3.66	3.71	3.76	3.86	3.94
600000		2.48	2.55	2.66	2.76	2.84	2.91	2.97	3.07	3.16	3.23	3.30	3.35	3.40	3.45	3.49	3.59	3.67
550000		2.30	2.36	2.47	2.55	2.62	2.69	2.74	2.84	2.92	2.99	3.04	3.10	3.14	3.19	3.23	3.31	3.39
500000		2.11	2.17	2.26	2.34	2.41	2.47	2.52	2.60	2.68	2.74	2.79	2.84	2.88	2.92	2.96	3.03	3.10
450000		1.92	1.97	2.06	2.13	2.19	2.24	2.29	2.36	2.43	2.49	2.53	2.58	2.62	2.65	2.68	2.75	2.81
400000		1.73	1.78	1.86	1.92	1.97	2.02	2.06	2.13	2.19	2.24	2.28	2.32	2.35	2.38	2.41	2.48	2.53
350000		1.54	1.58	1.65	1.70	1.75	1.79	1.82	1.88	1.94	1.98	2.02	2.05	2.08	2.11	2.13	2.19	2.23
300000		1.34	1.37	1.43	1.48	1.52	1.55	1.58	1.64	1.68	1.72	1.75	1.78	1.80	1.83	1.85	1.90	1.94
250000		1.14	1.17	1.21	1.25	1.29	1.32	1.34	1.38	1.42	1.45	1.48	1.50	1.52	1.54	1.56	1.60	1.63
211600	0000	.987	1.01	1.05	1.09	1.11	1.14	1.16	1.20	1.23	1.25	1.28	1.30	1.32	1.33	1.35	1.38	1.41
167806	000	.800	.819	.852	.878	.901	.920	.937	.966	.990	1.01	1.03	1.05	1.06	1.07	1.09	1.11	1.13
133077	00	.648	.663	.689	.710	.728	.743	.756	.780	.799	.815	.830	.842	.854	.864	.874	.895	.913
105535	0	.524	.537	.557	.574	.588	.600	.611	.629	.644	.657	.668	.679	.688	.696	.704	.720	.734
83693	1	.424	.434	.450	.463	.474	.484	.493	.507	.519	.530	.539	.547	.554	.560	.566	.580	.591
66371	2	.343	.351	.364	.374	.383	.391	.397	.409	.418	.427	.434	.440	.446	.451	.456	.466	.475
52635	3	.277	.283	.294	.302	.309	.315	.320	.330	.337	.344	.349	.354	.359	.363	.367	.375	.382
41741	4	.224	.229	.237	.244	.249	.254	.258	.265	.272	.277	.281	.285	.289	.292	.295	.302	.307
33102	5	.181	.185	.191	.197	.201	.205	.208	.214	.219	.223	.226	.230	.232	.235	.237	.243	.247
26251	6	.146	.149	.154	.159	.162	.165	.168	.172	.176	.179	.182	.185	.187	.189	.191	.195	.199

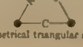
The table is useful in indicating the relative importance of reactance as compared with resistance as affecting line voltage conditions. Also when resistance volts have been determined (at 25°C) the reactance volts may be found by multiplying the resistance volts by the ratios given in the table for the spacing and size of conductors contemplated.

The above ratios are based upon the 25 cycle resistance values for hard drawn copper (97.3% conductivity) at 25°C (77°F) as given in table V. The ratio at any other frequency than 25 cycles is $\frac{f}{25}$ times the table values, f being the frequency.

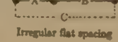
★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



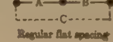
Unsymmetrical triangular spacing



Symmetrical triangular spacing



Irregular flat spacing



Regular flat spacing

TABLE XIV—RATIO OF 25 CYCLE REACTANCE TO 25 CYCLE RESISTANCE AT 25°C—(77°F)

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

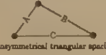
MULTIPLE LAYER CONDUCTORS—RESISTANCE AT 600 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (B & S) ALUMINUM	NUMBER OF WIRES		COPPER EQUIVALENT CIRCULAR MILS OR A W G. BASED UPON COPPER 97% ALUMIN 61%	RATIO OF 25 CYCLE REACTANCE TO 25 CYCLE RESISTANCE — DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																			
	ALUM.	STEEL		2 FEET (0.61 M)	2.5 FEET (0.76 M)	3 FEET (0.91 M)	3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
1 590 000	54	7	1 000 000	3.00	3.18	3.34	3.47	3.59	3.78	3.93	4.07	4.18	4.28	4.45	4.59	4.72	4.82	4.92	5.00	5.08	5.15	5.31	5.44
1 510 500	54	7	950 000	2.86	3.05	3.19	3.32	3.43	3.61	3.76	3.88	3.99	4.08	4.25	4.38	4.50	4.60	4.69	4.77	4.85	4.91	5.06	5.19
1 431 000	54	7	900 000	2.73	2.91	3.05	3.16	3.27	3.44	3.58	3.70	3.80	3.89	4.05	4.18	4.28	4.38	4.47	4.54	4.61	4.68	4.82	4.94
1 351 500	54	7	850 000	2.60	2.76	2.90	3.01	3.11	3.27	3.40	3.51	3.61	3.69	3.84	3.96	4.07	4.16	4.24	4.31	4.38	4.44	4.57	4.68
1 272 000	54	7	800 000	2.47	2.62	2.75	2.85	2.94	3.10	3.22	3.33	3.42	3.50	3.64	3.75	3.85	3.94	4.01	4.08	4.14	4.20	4.32	4.43
1 192 500	54	7	750 000	2.33	2.48	2.60	2.70	2.78	2.93	3.04	3.14	3.23	3.30	3.43	3.54	3.63	3.71	3.78	3.85	3.90	3.96	4.07	4.17
1 113 000	54	7	700 000	2.20	2.33	2.44	2.53	2.61	2.75	2.86	2.95	3.03	3.10	3.22	3.32	3.41	3.48	3.55	3.61	3.66	3.71	3.82	3.92
1 033 500	54	7	650 000	2.06	2.18	2.29	2.37	2.45	2.57	2.67	2.76	2.83	2.90	3.01	3.10	3.18	3.25	3.31	3.37	3.42	3.47	3.57	3.66
954 000	54	7	600 000	1.92	2.04	2.13	2.21	2.28	2.40	2.49	2.57	2.64	2.70	2.80	2.89	2.96	3.03	3.08	3.13	3.18	3.22	3.32	3.40
900 000	54	7	566 000	1.83	1.94	2.03	2.10	2.17	2.28	2.36	2.44	2.50	2.56	2.66	2.74	2.81	2.87	2.93	2.97	3.02	3.06	3.15	3.22
874 500	54	7	550 000	1.79	1.89	1.98	2.05	2.11	2.22	2.30	2.38	2.44	2.50	2.59	2.67	2.74	2.80	2.85	2.90	2.94	2.98	3.06	3.14
795 000	54	7	500 000	1.64	1.74	1.82	1.88	1.94	2.04	2.11	2.18	2.24	2.29	2.37	2.45	2.51	2.56	2.61	2.65	2.69	2.73	2.80	2.87
715 500	54	7	450 000	1.50	1.58	1.66	1.71	1.77	1.85	1.92	1.98	2.03	2.08	2.16	2.22	2.28	2.33	2.37	2.41	2.44	2.47	2.54	2.60
666 600	54	7	419 000	1.41	1.49	1.56	1.61	1.66	1.74	1.80	1.86	1.91	1.95	2.02	2.08	2.13	2.18	2.22	2.26	2.29	2.32	2.38	2.44
636 000	54	7	400 000	1.35	1.43	1.49	1.54	1.59	1.67	1.73	1.78	1.83	1.87	1.94	1.99	2.04	2.09	2.12	2.16	2.19	2.22	2.28	2.33
605 000	54	7	380 500	1.29	1.37	1.43	1.48	1.52	1.59	1.65	1.70	1.75	1.78	1.85	1.91	1.95	1.99	2.03	2.06	2.09	2.12	2.18	2.23
556 500	30	7	350 000	1.19	1.26	1.32	1.36	1.40	1.47	1.53	1.57	1.61	1.65	1.71	1.76	1.80	1.84	1.88	1.90	1.93	1.96	2.01	2.06
556 500	26	7	350 000	1.21	1.28	1.33	1.38	1.42	1.49	1.54	1.59	1.63	1.66	1.72	1.77	1.82	1.86	1.89	1.92	1.95	1.97	2.03	2.07
518 000	42	19	326 000	1.10	1.16	1.21	1.26	1.29	1.36	1.41	1.45	1.49	1.52	1.58	1.63	1.67	1.70	1.73	1.76	1.79	1.81	1.86	1.90
500 000	30	7	314 500	1.09	1.15	1.20	1.24	1.28	1.34	1.39	1.43	1.46	1.50	1.55	1.60	1.63	1.67	1.70	1.73	1.75	1.77	1.82	1.86
477 000	30	7	300 000	1.04	1.10	1 15	1.19	1.22	1.28	1.33	1.37	1.40	1.43	1.49	1.53	1.57	1.60	1.63	1.65	1.68	1.70	1.75	1.78
477 000	26	7	300 000	1.06	1.11	1.16	1.20	1.24	1.29	1.34	1.38	1.41	1.45	1.50	1.54	1.58	1.61	1.64	1.66	1.69	1.71	1.76	1.80
397 500	30	7	250 000	.892	.940	.980	1.01	1.04	1.09	1.13	1.16	1.19	1.22	1.26	1.30	1.33	1.35	1.38	1.40	1.42	1.44	1.48	1.51
397 500	26	7	250 000	.902	.950	.990	1.02	1.05	1.10	1.14	1.17	1.20	1.23	1.27	1.31	1.34	1.36	1.39	1.41	1.43	1.45	1.49	1.52
336 400	30	7	0000	.771	.811	.845	.873	.897	.938	.971	.999	1.02	1.04	1.08	1.11	1.14	1.16	1.18	1.20	1.22	1.23	1.26	1.29
336 400	26	7	0000	.779	.820	.853	.881	.905	.946	.980	1.01	1.03	1.05	1.09	1.12	1.15	1.17	1 19	1.21	1.22	1.24	1.27	1.30
300 000	30	7	188 800	.697	.734	763	.788	.810	.846	.876	.901	.922	.941	974	1.00	1.03	1.05	1.06	1.08	1.09	1.11	1.14	1.16
300 000	26	7	188 800	.705	.742	.771	.796	.818	.854	.884	.909	.930	.949	.982	1.01	1.03	1.05	1.07	1.09	1 10	1.12	1.15	1.17
266 800	26	7	000	.634	.666	.693	.715	.734	.767	.793	.815	.834	.851	.881	.905	.925	.943	.959	.974	.987	.999	1.03	1.05
SINGLE LAYER CONDUCTORS—CURRENT DENSITY 0 AMPERES PER SQUARE INCH																							
266 800	6	7	000	.655	.687	.714	.736	.755	.787	.814	.836	.855	.872	.901	.926	.946	.964	.981	.995	1.01	1.02	1.05	1.07
0000	6	1	00	.573	.599	.619	.637	.652	.678	.699	.716	.731	.745	.768	.787	.804	.818	.830	.842	.852	.862	.883	.900
000	6	1	0	.466	.487	.503	.517	.529	.550	.566	.580	.592	.603	.621	.636	.649	.661	.671	.680	.688	.696	.712	.726
00	6	1	1	.379	.395	.408	.419	.428	.444	.458	.469	.478	.487	.501	.513	.524	.533	.541	.548	.554	.560	.574	.584
0	6	1	2	.307	.320	.330	.339	.347	.359	.370	.378	.386	.393	.404	.414	.422	.429	.436	.441	.447	.451	.462	.470
1	6	1	3	.248	.258	.267	.273	.279	.290	.298	.305	.311	.316	.325	.333	.339	.345	.350	.355	.359	.363	.371	.378
2	6	1	4	.200	.209	.215	.221	.225	.233	.240	.245	.250	.255	.262	.268	.273	.277	.281	.285	.288	.291	.298	.303
3	6	1	5	.162	.168	.173	.178	.182	.188	.193	.197	.201	.205	.210	.215	.219	.223	.226	.229	231	.234	.239	.243
4	6	1	6	.131	.136	.140	.143	.146	.151	.156	.159	.162	.165	.169	.173	.176	.179	.182	.184	.186	.188	192	.195
5	6	1	7	.105	.109	.113	.116	.118	.122	.125	.128	.130	.132	.136	.139	.142	.144	.146	.148	.149	151	154	.157
6	6	1	8	.0852	.0884	.0910	.0931	.0950	.0982	.101	.103	.105	.107	.109	.112	.114	.116	.117	.119	.120	.121	.124	.126
SINGLE LAYER CONDUCTORS—CURRENT DENSITY 600 AMPERES PER SQUARE INCH																							
266 800	6	7	000	.670	.702	.728	.750	.770	.802	.828	.850	.869	.886	.914	.939	.959	.977	.993	1.01	1.02	1.03	1.06	1.08
0000	6	1	00	.585	.611	.632	.649	.664	.689	.710	.727	.742	756	.778	.797	.814	.828	.840	.852	.862	.871	.892	.909
000	6	1	0	.473	.493	.510	.523	.535	.555	.572	.586	.598	.608	.626	.641	.654	.666	.676	.684	.693	.700	.717	.730
00	6	1	1	.383	.399	.412	.423	.433	.449	.462	.473	.482	.491	.505	.517	.527	.536	.544	.551	.558	.564	.577	.588
0	6	1	2	.310	.323	.333	.342	.349	.362	.373	.381	.389	.396	.407	.417	.425	.432	.438	.444	.449	.454	.464	.473
1	6	1	3	.250	.260	.269	.276	.282	.292	.300	.307	.313	.319	.328	.335	.342	.347	.352	.357	.361	.365	.373	.380
2	6	1	4	.202	.210	.216	.222	.227	.235	.241	.247	.251	.256	.263	.269	.274	.279	.283	.286	.289	.292	.299	.305
3	6	1	5	.162	.169	.174	.178	.182	.189	.194	.198	.202	.205	.211	.216	.220	.224	.227	.229	.232	.234	.240	.244
4	6	1	6	.131	.136	.140	.144	.147	.152	.156	.159	.162	.165	.169	.173	.177	.179	.182	.184	.186	.188	.192	.196
5	6	1	7	.106	.110	.113	.116	.118	.122	.126	.128	.131	.133	.136	.139	.142	.144	.146	.148	.150	.151	.154	.157
6	6	1	8	.0855	.0887	.0913	.0934	.0954	.0985	.101	.103	.105	.107	.110	.112	.114	.116	.118	.119	.120	.121	.124	.126
SINGLE LAYER CONDUCTORS—CURRENT DENSITY 1200 AMPERES PER SQUARE INCH																							
266 800	6	7	000	.715	.745	.769	.790	.807	.837	.862	.882	.900	.916	.943	.966	.985	1.00	1.02	1.03	1.04	1.05	1.08	1.10
0000	6	1	00	.589	.614	.634	.651	.665	.690	.710	.726	.741	.754	.776	.794	.810	.823	.835	.846	.856	.865	.885	.902
000	6	1	0	.485	.505	.521	.534	.546	.566	.582	.595	.607	.617	.635	.650	.663	.674	.683	.692	.700	.707	.724	.737
00	6	1	1	.395	.411	.424	.435	.444	.460	.473	.484	.493	.501	.516	.527	.538	.546	.554	.561	.568	.574	.587	.597
0	6	1	2	.319	.332	.342	.351	.358	.371	.381	.390	.398	.404	.416	.425	.433	.440	.447	.452	.457	.462	.472	.481
1	6	1	3	.256	.266	.275	.280	.287	.297	.306	.313	.319	.324	.333	.341	.347	.353	.358	.362	.366	.370	.378	.385
2	6	1	4	.205	.213	.220	.224	.230	.238	.244	.250	.255	.259	.266	.272	.277	.282	.286	.289	.293	.296	.302	.308
3	6	1	5	.164	.170	.176	.180	.184	.190	.195	.200	.204	.207	.213	.217	.221	.225	.228	.231	.234	.236	.241	.246
4	6	1	6	.132	.137	.141	.144	.147	.152	.156	.160	.163	.165	.170	.174	.177	.180	.182	.185	.187	.189	.193	.196
5	6	1	7	.107	.111	.114	.117	.119	.123	.126	.129	.132	.134	.137	.140	.143	.145	.147	.149	.151	.152	.155	.158
6	6	1	8	.0861	.0893	.0919	.0941	.0960	.0991	.102	.104	.106	.108	.110	.113	.115	.117	.118	.120	.121	.122	.125	.127

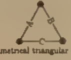
By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The table is useful in indicating the relative importance of reactance as compared with resistance as affecting line voltage conditions. Also when resistance volts have been determined (at 25°C) the reactance volts may be found by multiplying the resistance volts by the ratios given in the table for the spacing and size of conductors contemplated.

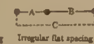
★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



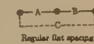
Unsymmetrical triangular spacing



Symmetrical triangular spacing



Irregular flat spacing



Regular flat spacing

TABLE XV—RATIO OF 60 CYCLE REACTANCE TO 60 CYCLE RESISTANCE AT 25°C—(77°F)

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	RATIO OF 60 CYCLE REACTANCE TO 60 CYCLE RESISTANCE AT 25°C													
				DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE (B&S)			2 INCHES (5.1 CM.)	4 INCHES (10.2 CM.)	6 INCHES (15.2 CM.)	8 INCHES (20.3 CM.)	10 INCHES (25.4 CM.)	12 INCHES (30.5 CM.)	15 INCHES (38.1 CM.)	18 INCHES (45.7 CM.)	21 INCHES (53.3 CM.)	24 INCHES (61.0 CM.)	27 INCHES (68.6 CM.)	30 INCHES (76.2 CM.)	33 INCHES (83.8 CM.)	36 INCHES (91.4 CM.)
2000000		127	1.631	3.70	5.93	7.24	8.16	8.88	9.47	10.2	10.8	11.3	11.7	12.1	12.4	12.7	13.0
1900000		127	1.590	3.66	5.82	7.08	7.98	8.67	9.24	9.93	10.5	11.0	11.4	11.8	12.1	12.4	12.7
1800000		127	1.548	3.61	5.69	6.91	7.77	8.44	8.99	9.66	10.2	10.7	11.1	11.4	11.7	12.0	12.3
1700000		127	1.504	3.55	5.55	6.72	7.55	8.20	8.72	9.37	9.89	10.3	10.7	11.1	11.4	11.6	11.9
1600000		127	1.459	3.49	5.40	6.52	7.32	7.94	8.44	9.06	9.56	9.99	10.4	10.7	11.0	11.2	11.5
1500000		91	1.412	3.42	5.25	6.32	7.07	7.66	8.14	8.73	9.21	9.62	9.97	10.3	10.6	10.8	11.0
1400000		91	1.364	3.33	5.07	6.08	6.80	7.36	7.82	8.38	8.83	9.22	9.56	9.85	10.1	10.4	10.6
1300000		91	1.315	3.24	4.88	5.84	6.52	7.04	7.47	8.00	8.43	8.80	9.11	9.39	9.64	9.87	10.1
1200000		91	1.263	3.13	4.67	5.57	6.20	6.70	7.10	7.60	8.00	8.35	8.64	8.90	9.14	9.35	9.54
1100000		91	1.209	3.00	4.44	5.27	5.87	6.33	6.71	7.17	7.55	7.86	8.14	8.38	8.60	8.80	8.98
1000000		61	1.152	2.87	4.19	4.97	5.52	5.94	6.29	6.71	7.06	7.36	7.61	7.84	8.04	8.22	8.39
950000		61	1.123	2.79	4.06	4.80	5.32	5.73	6.07	6.47	6.81	7.09	7.33	7.55	7.74	7.91	8.07
900000		61	1.093	2.71	3.92	4.63	5.13	5.52	5.83	6.22	6.54	6.81	7.04	7.25	7.43	7.60	7.75
850000		61	1.062	2.63	3.77	4.45	4.92	5.29	5.59	5.96	6.27	6.52	6.74	6.94	7.11	7.27	7.41
800000		61	1.031	2.54	3.62	4.26	4.71	5.06	5.35	5.70	5.98	6.23	6.44	6.62	6.79	6.94	7.07
750000		61	.998	2.44	3.47	4.07	4.49	4.82	5.09	5.42	5.69	5.92	6.12	6.30	6.45	6.59	6.72
700000		61	.964	2.34	3.30	3.87	4.27	4.58	4.83	5.14	5.39	5.61	5.80	5.96	6.11	6.24	6.36
650000		61	.929	2.23	3.13	3.66	4.03	4.32	4.56	4.85	5.09	5.29	5.46	5.61	5.75	5.87	5.99
600000		37	.891	2.13	2.96	3.45	3.80	4.07	4.29	4.56	4.78	4.96	5.12	5.27	5.39	5.51	5.61
550000		37	.853	2.01	2.78	3.23	3.55	3.80	4.00	4.25	4.45	4.62	4.77	4.90	5.02	5.12	5.22
500000		37	.814	1.88	2.59	3.00	3.29	3.51	3.70	3.93	4.11	4.27	4.40	4.52	4.63	4.73	4.81
450000		37	.772	1.75	2.39	2.76	3.02	3.23	3.39	3.60	3.76	3.91	4.03	4.14	4.23	4.32	4.40
400000		19	.725	1.62	2.19	2.52	2.76	2.94	3.09	3.27	3.42	3.55	3.66	3.75	3.84	3.92	3.99
350000		19	.679	1.47	1.97	2.26	2.47	2.63	2.76	2.92	3.05	3.16	3.26	3.34	3.42	3.49	3.55
300000		19	.628	1.31	1.74	1.99	2.17	2.31	2.42	2.56	2.67	2.76	2.85	2.92	2.99	3.04	3.10
250000		19	.574	1.14	1.50	1.71	1.86	1.97	2.07	2.18	2.28	2.36	2.43	2.49	2.54	2.59	2.63
211600	0000	7	.522	1.03	1.33	1.51	1.64	1.73	1.81	1.91	1.99	2.06	2.12	2.17	2.21	2.26	2.29
167806	000	7	.464	.859	1.10	1.24	1.34	1.42	1.48	1.56	1.62	1.68	1.72	1.76	1.80	1.83	1.86
133077	00	7	.414	.714	.905	1.02	1.10	1.16	1.21	2.27	1.32	1.36	1.40	1.43	1.46	1.49	1.51
105535	0	7	.368	.592	.743	.832	.895	.944	.984	1.03	1.07	1.11	1.14	1.16	1.18	1.21	1.22
83693	1	7	.328	.489	.610	.680	.730	.769	.800	.839	.871	.897	.921	.941	.959	.976	.991
66371	2	7	.292	.404	.500	.555	.595	.626	.651	.682	.707	.728	.746	.762	.777	.790	.802
52635	3	7	.260	.333	.409	.453	.485	.509	.529	.553	.573	.590	.604	.617	.629	.639	.649
41741	4	7	.232	.274	.334	.369	.394	.414	.429	.449	.465	.478	.489	.500	.509	.517	.525
33102	5	7	.206	.226	.273	.301	.321	.336	.349	.364	.376	.387	.396	.404	.411	.418	.424
26251	6	7	.184	.185	.223	.245	.261	.273	.283	.295	.305	.313	.320	.327	.333	.338	.343

		DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M.)	23 FEET (7.01 M.)	25 FEET (7.62 M.)	30 FEET (9.14 M.)	[illegible] FEET (10.67 M.)
2000000		13.5	13.9	14.7	15.2	15.7	16.2	16.5	17.2	17.7	18.2	18.6	18.9	19.3	19.6	19.8	20.4	20.9
1900000		13.1	13.6	14.3	14.8	15.3	15.7	16.1	16.7	17.2	17.7	18.1	18.4	18.7	19.0	19.3	19.8	20.3
1800000		12.7	13.2	13.8	14.4	14.8	15.2	15.6	16.2	16.7	17.1	17.5	17.8	18.1	18.4	18.6	19.2	19.7
1700000		12.3	12.7	13.4	13.9	14.3	14.7	15.1	15.6	16.1	16.5	16.9	17.2	17.5	17.8	18.0	18.5	19.0
1600000		11.9	12.3	12.9	13.4	13.8	14.2	14.5	15.1	15.5	15.9	16.3	16.6	16.9	17.1	17.3	17.8	18.3
1500000		11.5	11.8	12.4	12.9	13.3	13.6	13.9	14.5	14.9	15.3	15.6	15.9	16.2	16.4	16.6	17.1	17.5
1400000		11.0	11.3	11.9	12.3	12.7	13.0	13.3	13.8	14.2	14.6	14.9	15.2	15.4	15.7	15.9	16.3	16.7
1300000		10.4	10.8	11.3	11.7	12.1	12.4	12.7	13.2	13.5	13.9	14.2	14.4	14.7	14.9	15.1	15.5	15.9
1200000		9.89	10.2	10.7	11.1	11.4	11.7	12.0	12.4	12.8	13.1	13.4	13.6	13.9	14.1	14.3	14.7	15.0
1100000		9.30	9.57	10.0	10.4	10.7	11.0	11.3	11.7	12.0	12.3	12.6	12.8	13.0	13.2	13.4	13.7	14.1
1000000		8.68	8.93	9.36	9.71	10.0	10.3	10.5	10.9	11.2	11.5	11.7	11.9	12.1	12.3	12.4	12.8	13.1
950000		8.35	8.60	9.01	9.34	9.62	9.86	10.1	10.4	10.8	11.0	11.2	11.4	11.6	11.8	11.9	12.3	12.6
900000		8.02	8.25	8.64	8.96	9.23	9.46	9.66	10.0	10.3	10.6	10.8	11.0	11.1	11.3	11.4	11.8	12.0
850000		7.67	7.89	8.26	8.56	8.82	9.04	9.24	9.57	9.84	10.1	10.3	10.5	10.6	10.8	10.9	11.2	11.5
800000		7.32	7.52	7.87	8.16	8.40	8.61	8.80	9.11	9.38	9.60	9.80	9.97	10.1	10.3	10.4	10.7	10.9
750000		6.95	7.15	7.48	7.75	7.98	8.17	8.35	8.65	8.89	9.11	9.29	9.46	9.60	9.74	9.86	10.1	10.4
700000		6.57	6.76	7.07	7.32	7.54	7.72	7.89	8.17	8.40	8.60	8.77	8.93	9.07	9.19	9.31	9.56	9.78
650000		6.19	6.36	6.65	6.89	7.09	7.26	7.41	7.67	7.89	8.08	8.24	8.38	8.51	8.63	8.74	8.98	9.18
600000		5.80	5.96	6.23	6.45	6.63	6.79	6.94	7.18	7.38	7.55	7.70	7.84	7.96	8.07	8.17	8.39	8.57
550000		5.39	5.54	5.79	5.99	6.16	6.31	6.44	6.66	6.85	7.01	7.14	7.27	7.38	7.48	7.57	7.77	7.95
500000		4.97	5.11	5.33	5.52	5.67	5.81	5.93	6.13	6.30	6.45	6.57	6.69	6.79	6.88	6.96	7.15	7.30
450000		4.54	4.66	4.87	5.03	5.18	5.30	5.41	5.59	5.74	5.87	5.99	6.09	6.18	6.27	6.34	6.51	6.65
400000		4.11	4.22	4.40	4.55	4.68	4.79	4.89	5.05	5.19	5.30	5.41	5.50	5.58	5.65	5.72	5.87	6.00
350000		3.66	3.75	3.91	4.05	4.16	4.25	4.34	4.48	4.60	4.70	4.79	4.87	4.94	5.01	5.07	5.20	5.31
300000		3.19	3.28	3.41	3.53	3.62	3.70	3.78	3.90	4.00	4.09	4.17	4.24	4.30	4.35	4.41	4.52	4.61
250000		2.71	2.78	2.90	2.99	3.07	3.14	3.20	3.30	3.39	3.46	3.53	3.59	3.64	3.68	3.73	3.82	3.90
211600	0000	2.36	2.42	2.52	2.60	2.66	2.72	2.77	2.86	2.94	3.00	3.05	3.10	3.14	3.18	3.22	3.30	3.37
167806	000	1.92	1.96	2.04	2.10	2.16	2.20	2.24	2.31	2.37	2.42	2.46	2.50	2.54	2.57	2.60	2.66	2.72
133077	00	1.55	1.59	1.65	1.70	1.74	1.78	1.81	1.87	1.91	1.95	1.99	2.02	2.05	2.07	2.10	2.15	2.19
105535	0	1.26	1.29	1.34	1.38	1.41	1.44	1.46	1.51	1.54	1.58	1.60	1.63	1.65	1.67	1.69	1.73	1.76
83693	1	1.02	1.04	1.08	1.11	1.14	1.16	1.18	1.22	1.25	1.27	1.29	1.31	1.33	1.34	1.36	1.39	1.42
66371	2	.823	.842	.872	.897	.919	.937	.953	.981	1.00	1.02	1.04	1.06	1.07	1.08	1.09	1.12	1.14
52635	3	.666	.680	.704	.724	.741	.756	.769	.791	.809	.824	.838	.850	.861	.871	.880	.900	.917
41741	4	.538	.549	.569	.585	.598	.609	.620	.637	.651	.664	.675	.684	.693	.701	.708	.724	.737
33102	5	.435	.444	.459	.472	.482	.491	.499	.513	.525	.534	.543	.551	.558	.564	.570	.582	.593
26251	6	.351	.358	.370	.380	.389	.396	.402	.413	.422	.430	.437	.443	.448	.453	.458	.468	.476

The table is useful in indicating the relative importance of reactance as compared with resistance as affecting line voltage conditions. Also when resistance volts have been determined (at 25°C) the reactance volts may be found by multiplying the resistance volts by the ratios given in the table for the spacing and size of conductors contemplated.

The above ratios are based upon the 60 cycle resistance values for hard drawn copper (97.3% conductivity) at 25°C (77°F) as given in table V. The ratio at any other frequency than 60 cycles is $\frac{f}{60}$ times the table values, f being the frequency.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing

Symmetrical triangular spacing

Irregular flat spacing

Regular flat spacing

TABLE XVI—RATIO OF 60 CYCLE REACTANCE TO 60 CYCLE RESISTANCE AT 25°C—(77°F)

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

MULTIPLE LAYER CONDUCTORS—RESISTANCE AT 600 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (B & S) (ALUMINUM)	NUMBER OF WIRES		COPPER EQUIVALENT CIRCULAR MILS OR A W G. BASED UPON COPPER 97% ALUMIN. 61%	RATIO OF 60 CYCLE REACTANCE TO 60 CYCLE RESISTANCE. DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																			
	ALUM.	STEEL		2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M.)	23 FEET (7.01 M.)	25 FEET (7.62 M.)	30 FEET (9.14 M.)	35 FEET (10.67 M.)
1 590 000	54	7	1 000000	7.02	7.46	7.83	8.14	8.41	8.85	9.21	9.53	9.79	10.0	10.4	10.8	11.1	11.3	11.5	11.7	11.9	12.1	12.4	12.8
1 510 500	54	7	950000	6.71	7.14	7.49	7.78	8.03	8.46	8.81	9.10	9.35	9.58	9.96	10.3	10.6	10.8	11.0	11.2	11.4	11.5	11.9	12.2
1 431 000	54	7	900000	6.42	6.83	7.16	7.43	7.67	8.08	8.41	8.68	8.93	9.14	9.51	9.81	10.1	10.3	10.5	10.7	10.8	11.0	11.3	11.6
1 351 500	54	7	850000	6.12	6.50	6.82	7.08	7.30	7.69	8.00	8.25	8.49	8.69	9.04	9.32	9.57	9.78	9.97	10.1	10.3	10.4	10.8	11.0
1 272 000	54	7	800000	5.82	6.18	6.47	6.72	6.94	7.30	7.59	7.84	8.05	8.24	8.56	8.83	9.06	9.27	9.44	9.61	9.76	9.89	10.2	10.4
1 192 500	54	7	750000	5.51	5.85	6.13	6.36	6.56	6.90	7.18	7.41	7.61	7.79	8.10	8.35	8.57	8.76	8.92	9.08	9.22	9.34	9.62	9.85
1 113000	54	7	700000	5.19	5.51	5.77	5.98	6.17	6.49	6.75	6.97	7.16	7.32	7.61	7.85	8.05	8.22	8.38	8.52	8.65	8.77	9.03	9.25
1 033500	54	7	650000	4.87	5.16	5.40	5.60	5.78	6.07	6.31	6.52	6.69	6.85	7.11	7.33	7.52	7.68	7.83	7.96	8.08	8.19	8.43	8.64
954000	54	7	600000	4.56	4.83	5.05	5.24	5.41	5.67	5.90	6.09	6.25	6.39	6.64	6.84	7.01	7.17	7.30	7.42	7.54	7.63	7.86	8.05
900000	54	7	566000	4.34	4.60	4.80	4.98	5.14	5.39	5.60	5.78	5.93	6.07	6.30	6.49	6.66	6.80	6.93	7.05	7.15	7.25	7.46	7.63
874 500	54	7	550000	4.21	4.46	4.66	4.84	4.99	5.23	5.44	5.61	5.76	5.89	6.11	6.30	6.46	6.60	6.72	6.83	6.93	7.03	7.23	7.40
795000	54	7	500000	3.89	4.12	4.31	4.46	4.60	4.83	5.01	5.17	5.30	5.42	5.63	5.80	5.94	6.07	6.18	6.29	6.38	6.46	6.65	6.80
715500	54	7	450000	3.55	3.76	3.92	4.06	4.19	4.39	4.56	4.70	4.82	4.93	5.11	5.27	5.40	5.51	5.61	5.70	5.79	5.86	6.03	6.17
666600	54	7	419000	3.34	3.53	3.69	3.82	3.93	4.12	4.28	4.41	4.52	4.62	4.80	4.94	5.06	5.17	5.26	5.35	5.42	5.49	5.65	5.78
636000	54	7	400000	3.20	3.38	3.53	3.65	3.76	3.94	4.09	4.22	4.33	4.42	4.59	4.72	4.84	4.94	5.03	5.11	5.18	5.25	5.40	5.52
605000	54	7	380500	3.06	3.24	3.38	3.49	3.60	3.77	3.91	4.03	4.13	4.22	4.38	4.51	4.62	4.72	4.80	4.88	4.95	5.01	5.15	5.27
556500	30	7	350000	2.87	3.03	3.16	3.27	3.37	3.53	3.66	3.77	3.87	3.95	4.10	4.22	4.33	4.42	4.50	4.57	4.63	4.69	4.83	4.94
556500	26	7	350000	2.90	3.06	3.20	3.31	3.40	3.57	3.70	3.81	3.91	3.99	4.14	4.26	4.36	4.45	4.53	4.60	4.67	4.73	4.86	4.97
518000	42	19	326000	2.64	2.79	2.91	3.02	3.11	3.26	3.38	3.48	3.57	3.65	3.79	3.90	4.00	4.08	4.16	4.22	4.28	4.34	4.46	4.57
500000	30	7	314500	2.61	2.76	2.88	2.97	3.06	3.21	3.33	3.43	3.51	3.59	3.72	3.83	3.92	4.00	4.08	4.14	4.20	4.25	4.37	4.47
477 000	30	7	300000	2.51	2.65	2.76	2.85	2.94	3.08	3.19	3.28	3.37	3.44	3.56	3.67	3.76	3.83	3.90	3.97	4.02	4.07	4.19	4.28
477000	26	7	300000	2.54	2.67	2.79	2.88	2.97	3.10	3.22	3.31	3.40	3.47	3.59	3.70	3.79	3.86	3.93	3.99	4.05	4.10	4.22	4.31
397 500	30	7	250000	2.14	2.26	2.35	2.43	2.50	2.61	2.71	2.79	2.86	2.92	3.02	3.11	3.18	3.25	3.31	3.36	3.40	3.45	3.54	3.62
397 500	26	7	250000	2.16	2.28	2.38	2.45	2.52	2.64	2.73	2.81	2.88	2.94	3.05	3.13	3.21	3.27	3.33	3.38	3.43	3.47	3.56	3.64
336400	30	7	0000	1.85	1.95	2.03	2.09	2.15	2.25	2.33	2.40	2.46	2.51	2.60	2.67	2.73	2.79	2.83	2.88	2.92	2.95	3.03	3.10
336400	26	7	0000	1.87	1.97	2.05	2.11	2.17	2.27	2.35	2.42	2.48	2.53	2.62	2.69	2.75	2.81	2.86	2.90	2.94	2.97	3.05	3.12
300000	30	7	188800	1.67	1.76	1.83	1.89	1.94	2.03	2.10	2.16	2.21	2.26	2.34	2.40	2.46	2.51	2.55	2.59	2.63	2.66	2.73	2.79
300 000	26	7	188800	1.69	1.78	1.85	1.91	1.96	2.05	2.12	2.18	2.23	2.28	2.36	2.42	2.48	2.53	2.57	2.61	2.64	2.68	2.75	2.81
266 800	26	7	000	1.52	1.60	1.66	1.72	1.76	1.84	1.90	1.96	2.00	2.04	2.11	2.17	2.22	2.26	2.30	2.34	2.37	2.40	2.46	2.51

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 0 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUM.	STEEL	COPPER EQUIVALENT	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET	30 FEET	35 FEET
266 800	6	7	000	1.57	1.64	1.71	1.76	1.81	1.88	1.95	2.00	2.05	2.09	2.16	2.21	2.26	2.31	2.35	2.38	2.41	2.44	2.50	2.56
0000	6	1	00	1.37	1.43	1.48	1.52	1.56	1.62	1.67	1.71	1.75	1.78	1.83	1.88	1.92	1.95	1.98	2.01	2.03	2.06	2.11	2.15
000	6	1	0	1.11	1.16	1.20	1.24	1.26	1.31	1.35	1.39	1.41	1.44	1.48	1.52	1.55	1.58	1.60	1.62	1.64	1.66	1.70	1.73
00	6	1	1	.905	.943	.974	1.00	1.02	1.06	1.09	1.12	1.14	1.16	1.20	1.23	1.25	1.27	1.29	1.31	1.32	1.34	1.37	1.40
0	6	1	2	.734	.765	.790	.810	.829	.859	.884	.905	.923	.939	.967	.990	1.01	1.03	1.04	1.06	1.07	1.08	1.10	1.13
1	6	1	3	.594	.619	.638	.655	.669	.694	.714	.730	.745	.757	.779	.798	.813	.827	.839	.850	.859	.868	.888	.904
2	6	1	4	.481	.500	.516	.529	.540	.560	.576	.589	.600	.610	.628	.642	.655	.665	.675	.684	.691	.699	.714	.728
3	6	1	5	.388	.403	.416	.426	.435	.450	.463	.473	.482	.490	.504	.516	.525	.534	.542	.548	.555	.560	.573	.583
4	6	1	6	.313	.325	.335	.344	.351	.363	.373	.381	.388	.395	.406	.415	.423	.429	.435	.441	.446	.450	.460	.468
5	6	1	7	.253	.262	.270	.277	.283	.292	.300	.307	.312	.317	.326	.333	.339	.345	.350	.354	.358	.361	.369	.376
6	6	1	8	.204	.212	.218	.223	.228	.236	.242	.247	.252	.256	.263	.268	.273	.277	.281	.285	.288	.291	.297	.302

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 600 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUM.	STEEL	COPPER EQUIVALENT	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET	30 FEET	35 FEET
266800	6	7	000	1.56	1.64	1.70	1.75	1.80	1.87	1.93	1.98	2.03	2.07	2.13	2.19	2.24	2.28	2.32	2.35	2.38	2.41	2.47	2.52
0000	6	1	00	1.35	1.41	1.46	1.50	1.53	1.59	1.64	1.68	1.71	1.75	1.80	1.84	1.88	1.91	1.94	1.97	1.99	2.01	2.06	2.10
000	6	1	0	1.10	1.15	1.19	1.22	1.25	1.29	1.33	1.36	1.39	1.42	1.46	1.49	1.52	1.55	1.57	1.59	1.61	1.63	1.67	1.70
00	6	1	1	.903	.940	.971	.997	1.02	1.06	1.09	1.11	1.14	1.16	1.19	1.22	1.24	1.26	1.28	1.30	1.32	1.33	1.36	1.39
0	6	1	2	.737	.768	.793	.813	.832	.862	.887	.907	.926	.942	.969	.992	1.01	1.03	1.04	1.06	1.07	1.08	1.11	1.13
1	6	1	3	.599	.623	.643	.659	.674	.698	.718	.734	.749	.762	.783	.802	.817	.831	.843	.853	.863	.872	.892	.909
2	6	1	4	.483	.502	.518	.531	.543	.562	.578	.591	.602	.612	.630	.644	.656	.667	.677	.685	.693	.700	.716	.729
3	6	1	5	.389	.405	.417	.428	.437	.452	.465	.475	.484	.492	.506	.517	.527	.536	.543	.550	.556	.562	.574	.585
4	6	1	6	.314	.326	.336	.344	.352	.364	.374	.382	.389	.396	.407	.416	.423	.430	.436	.442	.446	.451	.461	.469
5	6	1	7	.254	.263	.271	.278	.283	.293	.301	.307	.313	.318	.327	.334	.340	.346	.351	.355	.359	.362	.370	.377
6	6	1	8	.205	.213	.219	.224	.229	.236	.243	.248	.252	.256	.263	.269	.274	.278	.282	.285	.288	.291	.298	.303

SINGLE LAYER CONDUCTORS—CURRENT DENSITY 1200 AMPERES PER SQUARE INCH

CIRCULAR MILS OR A W G (ALUMINUM)	ALUM.	STEEL	COPPER EQUIVALENT	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	9 FEET	11 FEET	13 FEET	15 FEET	17 FEET	19 FEET	21 FEET	23 FEET	25 FEET	30 FEET	35 FEET
266 800	6	7	000	1.40	1.46	1.51	1.55	1.58	1.64	1.69	1.73	1.76	1.80	1.85	1.89	1.93	1.96	1.99	2.02	2.04	2.06	2.11	2.15
0000	6	1	00	1.24	1.29	1.33	1.36	1.40	1.45	1.49	1.52	1.55	1.58	1.63	1.67	1.70	1.73	1.75	1.78	1.80	1.82	1.86	1.89
000	6	1	0	1.06	1.11	1.14	1.17	1.20	1.24	1.28	1.31	1.33	1.35	1.39	1.43	1.45	1.48	1.50	1.52	1.54	1.55	1.59	1.62
00	6	1	1	.896	.932	.962	.986	1.01	1.04	1.07	1.10	1.12	1.14	1.17	1.20	1.22	1.24	1.26	1.27	1.29	1.30	1.33	1.36
0	6	1	2	.743	.773	.797	.817	.834	.864	.888	.908	.926	.941	.968	.990	1.01	1.03	1.04	1.05	1.07	1.08	1.10	1.12
1	6	1	3	.602	.625	.645	.657	.675	.699	.718	.734	.748	.761	.782	.800	.815	.828	.840	.851	.860	.869	.888	.905
2	6	1	4	.486	.505	.520	.530	.544	.563	.579	.592	.603	.613	.630	.644	.657	.667	.677	.685	.693	.700	.716	.728
3	6	1	5	.391	.407	.419	.429	.438	.454	.466	.476	.485	.493	.507	.519	.528	.537	.544	.551	.557	.563	.575	.586
4	6	1	6	.315	.327	.337	.345	.353	.365	.375	.383	.390	.397	.407	.417	.424	.431	.437	.442	.447	.452	.462	.470
5	6	1	7	.256	.266	.273	.280	.286	.295	.303	.310	.316	.321	.329	.337	.343	.348	.353	.357	.361	.364	.373	.379
6	6	1	8	.207	.214	.220	.226	.230	.238	.244	.249	.254	.258	.265	.270	.275	.280	.283	.287	.290	.293	.299	.304

By single layer conductors is meant conductors with one layer of aluminum over the steel core. By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.

The table is useful in indicating the relative importance of reactance as compared with resistance as affecting line voltage conditions. Also when resistance volts have been determined (at 25°C) the reactance volts may be found by multiplying the resistance volts by the ratios given in the table for the spacing and size of conductors contemplated.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XVII—CAPACITANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR: CIRCULAR MILS	SIZE OF CONDUCTOR: AMERICAN WIRE GAUGE B&S	NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	CAPACITANCE C TO NEUTRAL IN MICROFARADS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE CAPACITANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES. DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
				2 INCHES (5.1 CM.)	4 INCHES (10.2 CM.)	6 INCHES (15.2 CM.)	8 INCHES (20.3 CM.)	10 INCHES (25.4 CM.)	12 INCHES (30.5 CM.)	15 INCHES (38.1 CM.)	18 INCHES (45.7 CM.)	21 INCHES (53.3 CM.)	24 INCHES (61.0 CM.)	27 INCHES (68.6 CM.)	30 INCHES (76.2 CM.)	33 INCHES (83.8 CM.)	36 INCHES (91.4 CM.)
2 000 000		127	1.631	.1354	.05785	.04524	.03934	.03577	.03331	.03074	.02892	.02754	.02645	.02555	.02481	.02417	.02361
1 900 000		127	1.590	.1271	.05682	.04463	.03889	.03540	.03299	.03047	.02868	.02732	.02625	.02537	.02463	.02400	.02345
1 800 000		127	1.548	.1197	.05578	.04402	.03843	.03502	.03266	.03019	.02843	.02710	.02604	.02518	.02445	.02383	.02329
1 700 000		127	1.504	.1130	.05472	.04339	.03796	.03463	.03232	.02990	.02817	.02686	.02582	.02497	.02426	.02365	.02311
1 600 000		127	1.459	.1069	.05365	.04274	.03747	.03422	.03197	.02960	.02790	.02662	.02560	.02476	.02406	.02346	.02293
1 500 000		91	1.412	.1012	.05255	.04206	.03695	.03380	.03160	.02928	.02762	.02636	.02536	.02454	.02385	.02326	.02274
1 400 000		91	1.364	.09601	.05143	.04137	.03643	.03336	.03122	.02895	.02733	.02610	.02512	.02431	.02363	.02305	.02255
1 300 000		91	1.315	.09112	.05030	.04066	.03588	.03290	.03082	.02860	.02702	.02582	.02486	.02407	.02340	.02283	.02233
1 200 000		91	1.263	.08651	.04913	.03991	.03530	.03242	.03039	.02824	.02670	.02552	.02458	.02381	.02316	.02260	.02211
1 100 000		91	1.209	.08211	.04792	.03914	.03470	.03191	.02995	.02786	.02636	.02521	.02429	.02354	.02290	.02236	.02188
1 000 000		61	1.152	.07783	.04666	.03831	.03405	.03136	.02947	.02744	.02599	.02487	.02398	.02324	.02262	.02209	.02162
950 000		61	1.123	.07577	.04602	.03789	.03372	.03108	.02922	.02723	.02579	.02469	.02381	.02309	.02248	.02195	.02149
900 000		61	1.093	.07375	.04536	.03745	.03338	.03079	.02896	.02701	.02559	.02451	.02364	.02293	.02232	.02180	.02135
850 000		61	1.062	.07174	.04469	.03700	.03302	.03049	.02870	.02677	.02538	.02432	.02347	.02276	.02217	.02165	.02121
800 000		61	1.031	.06975	.04400	.03653	.03265	.03018	.02842	.02653	.02517	.02412	.02328	.02259	.02200	.02150	.02106
750 000		61	.998	.06777	.04328	.03605	.03227	.02985	.02813	.02628	.02494	.02391	.02309	.02240	.02183	.02133	.02090
700 000		61	.964	.06579	.04255	.03555	.03187	.02951	.02783	.02602	.02470	.02369	.02288	.02221	.02164	.02116	.02073
650 000		61	.929	.06382	.04179	.03503	.03145	.02915	.02751	.02578	.02445	.02346	.02267	.02201	.02145	.02097	.02055
600 000		37	.891	.06177	.04098	.03446	.03100	.02876	.02716	.02543	.02418	.02321	.02243	.02179	.02124	.02077	.02036
550 000		37	.853	.05977	.04016	.03389	.03053	.02836	.02681	.02512	.02390	.02295	.02219	.02156	.02102	.02056	.02016
500 000		37	.814	.05775	.03930	.03328	.03004	.02794	.02643	.02483	.02360	.02267	.02193	.02131	.02079	.02034	.01995
450 000		37	.772	.05569	.03839	.03264	.02952	.02748	.02602	.02447	.02327	.02237	.02165	.02105	.02054	.02010	.01971
400 000		19	.725	.05345	.03738	.03191	.02892	.02697	.02556	.02402	.02290	.02203	.02133	.02075	.02025	.01982	.01945
350 000		19	.679	.05127	.03635	.03116	.02831	.02643	.02508	.02360	.02252	.02167	.02099	.02043	.01995	.01953	.01917
300 000		9	.628	.04898	.03523	.03034	.02763	.02584	.02455	.02313	.02209	.02128	.02062	.02008	.01961	.01921	.01886
250 000		9	.574	.04654	.03399	.02942	.02687	.02518	.02395	.02260	.02160	.02082	.02020	.01967	.01923	.01884	.01850
211 600	0000	7	.522	.04427	.03280	.02853	.02612	.02452	.02335	.02207	.02111	.02037	.01977	.01927	.01884	.01847	.01814
167 806	000	7	.464	.04179	.03145	.02751	.02527	.02377	.02267	.02145	.02055	.01985	.01928	.01880	.01839	.01804	.01773
133 077	00	7	.414	.03959	.03021	.02656	.02446	.02305	.02202	.02087	.02002	.01935	.01881	.01835	.01796	.01763	.01733
105 535	0	7	.368	.03762	.02907	.02567	.02371	.02238	.02141	.02032	.01951	.01888	.01836	.01793	.01756	.01723	.01695
83 693	1	7	.328	.03585	.02801	.02484	.02300	.02175	.02083	.01980	.01903	.01843	.01793	.01752	.01716	.01686	.01658
66 371	2	7	.292	.03424	.02702	.02407	.02234	.02115	.02028	.01930	.01857	.01800	.01753	.01713	.01679	.01650	.01623
52 635	3	7	.260	.03277	.02610	.02334	.02171	.02059	.01976	.01883	.01814	.01759	.01714	.01676	.01643	.01615	.01590
41 741	4	7	.232	.03142	.02525	.02265	.02111	.02006	.01927	.01838	.01772	.01719	.01676	.01640	.01609	.01582	.01558
33 102	5	7	.206	.03018	.02445	.02201	.02055	.01955	.01880	.01796	.01732	.01682	.01641	.01606	.01576	.01550	.01527
26 251	6	7	.184	.02904	.02369	.02139	.02002	.01906	.01835	.01755	.01694	.01646	.01606	.01573	.01545	.01520	.01497

CIRCULAR MILS	AWG B&S	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M.)
2 000 000		.02268	.02194	.02080	.01996	.01929	.01875	.01830	.01758	.01702	.01657	.01619	.01587	.01560	.01535	.01513	.01468	.01432
1 900 000		.02254	.02180	.02068	.01984	.01919	.01865	.01820	.01749	.01694	.01649	.01612	.01580	.01553	.01528	.01507	.01462	.01426
1 800 000		.02239	.02166	.02055	.01972	.01908	.01855	.01810	.01740	.01685	.01641	.01604	.01573	.01545	.01521	.01500	.01456	.01420
1 700 000		.02223	.02151	.02042	.01960	.01896	.01844	.01800	.01730	.01676	.01632	.01596	.01565	.01538	.01514	.01493	.01449	.01414
1 600 000		.02206	.02136	.02028	.01947	.01884	.01832	.01789	.01720	.01666	.01623	.01587	.01556	.01530	.01506	.01485	.01442	.01407
1 500 000		.02188	.02119	.02013	.01933	.01871	.01820	.01777	.01709	.01656	.01614	.01578	.01548	.01521	.01498	.01477	.01434	.01400
1 400 000		.02170	.02102	.01997	.01919	.01858	.01807	.01765	.01698	.01646	.01604	.01568	.01538	.01512	.01489	.01469	.01426	.01392
1 300 000		.02151	.02084	.01981	.01904	.01843	.01794	.01753	.01686	.01635	.01593	.01558	.01529	.01503	.01480	.01460	.01418	.01384
1 200 000		.02130	.02065	.01963	.01888	.01828	.01780	.01739	.01674	.01623	.01582	.01548	.01518	.01493	.01471	.01451	.01409	.01376
1 100 000		.02108	.02044	.01945	.01871	.01812	.01764	.01724	.01660	.01610	.01570	.01536	.01507	.01482	.01460	.01441	.01399	.01366
1 000 000		.02085	.02022	.01925	.01852	.01795	.01748	.01708	.01645	.01596	.01556	.01523	.01495	.01470	.01449	.01429	.01389	.01356
950 000		.02072	.02010	.01914	.01842	.01785	.01739	.01700	.01638	.01589	.01550	.01517	.01489	.01464	.01443	.01424	.01383	.01351
900 000		.02059	.01998	.01903	.01832	.01776	.01730	.01691	.01630	.01581	.01542	.01510	.01482	.01458	.01436	.01417	.01378	.01346
850 000		.02046	.01985	.01891	.01821	.01766	.01720	.01682	.01621	.01573	.01535	.01503	.01475	.01451	.01430	.01411	.01372	.01340
800 000		.02032	.01972	.01879	.01810	.01755	.01710	.01673	.01612	.01565	.01527	.01495	.01468	.01444	.01423	.01404	.01365	.01334
750 000		.02017	.01958	.01867	.01798	.01744	.01700	.01663	.01603	.01556	.01518	.01487	.01460	.01436	.01416	.01397	.01359	.01327
700 000		.02001	.01943	.01853	.01786	.01733	.01689	.01652	.01593	.01547	.01510	.01478	.01452	.01428	.01408	.01390	.01351	.01321
650 000		.01985	.01928	.01839	.01773	.01720	.01677	.01641	.01583	.01537	.01500	.01469	.01443	.01420	.01400	.01382	.01344	.01314
600 000		.01967	.01911	.01824	.01758	.01707	.01664	.01629	.01571	.01526	.01490	.01459	.01433	.01411	.01391	.01373	.01336	.01306
550 000		.01948	.01893	.01808	.01743	.01693	.01651	.01616	.01559	.01515	.01479	.01449	.01424	.01401	.01381	.01364	.01327	.01297
500 000		.01928	.01874	.01790	.01727	.01677	.01636	.01602	.01546	.01503	.01468	.01438	.01413	.01391	.01371	.01354	.01318	.01288
450 000		.01907	.01854	.01772	.01710	.01661	.01621	.01587	.01532	.01490	.01455	.01426	.01401	.01379	.01360	.01343	.01308	.01279
400 000		.01882	.01830	.01750	.01690	.01642	.01603	.01570	.01516	.01474	.01440	.01412	.01388	.01366	.01348	.01331	.01296	.01267
350 000		.01856	.01806	.01728	.01669	.01622	.01584	.01551	.01499	.01458	.01425	.01397	.01373	.01353	.01334	.01318	.01283	.01256
300 000		.01826	.01778	.01702	.01645	.01600	.01562	.01531	.01480	.01440	.01408	.01381	.01357	.01337	.01319	.01303	.01269	.01242
250 000		.01793	.01746	.01673	.01618	.01574	.01538	.01507	.01458	.01419	.01388	.01361	.01339	.01319	.01302	.01286	.01253	.01227
211 600	0000	.01759	.01714	.01644	.01591	.01548	.01513	.01484	.01436	.01398	.01368	.01342	.01320	.01301	.01284	.01269	.01237	.01211
167 806	000	.01720	.01677	.01610	.01559	.01518	.01484	.01456	.01410	.01373	.01344	.01319	.01298	.01279	.01263	.01248	.01217	.01192
133 077	00	.01683	.01641	.01577	.01528	.01488	.01456	.01429	.01384	.01349	.01321	.01297	.01276	.01258	.01242	.01228	.01198	.01174
105 535	0	.01647	.01607	.01545	.01498	.01460	.01429	.01403	.01360	.01326	.01299	.01275	.01256	.01238	.01223	.01209	.01180	.01156
83 693	1	.01612	.01574	.01515	.01469	.01433	.01403	.01378	.01336	.01304	.01277	.01255	.01235	.01219	.01204	.01190	.01162	.01139
66 371	2	.01579	.01543	.01486	.01442	.01407	.01378	.01354	.01314	.01282	.01256	.01235	.01216	.01200	.01185	.01172	.01145	.01123
52 635	3	.01548	.01513	.01458	.01416	.01382	.01354	.01330	.01292	.01261	.01236	.01215	.01197	.01181	.01167	.01155	.01128	.01107
41 741	4	.01517	.01484	.01431	.01390	.01357	.01331	.01308	.01270	.01241	.01217	.01196	.01179	.01163	.01150	.01138	.01112	.01091
33 102	5	.01488	.01456	.01405	.01365	.01334	.01308	.01286	.01250	.01221	.01198	.01178	.01161	.01146	.01133	.01121	.01096	.01076
26 251	6	.01460	.01429	.01379	.01342	.01311	.01286	.01265	.01230	.01202	.01179	.01160	.01144	.01129	.01117	.01105	.01081	.01061

The table values are derived from the exact equation $C = \dfrac{0.038829}{\log_{10}\left(\frac{D}{d} + \sqrt{\left(\frac{D}{d}\right)^2 - 1}\right)}$, d being the diameter of the conductor expressed in the same units as D.

When D is large compared with d, as is always the case in high-tension transmission lines employing bare conductors, the capacitance may be calculated, with negligible error, from the simplified equation $C = \dfrac{0.038829}{\log_{10} \dfrac{2\,D}{d}}$

The heavy zig-zag line shows the points at which the exact and simplified equations give the same result to the four significant figures of the table, the exact equation having been used in that portion of the table above and to the left of the zig-zag line and the simplified equation in that portion below and to the right of the zig-zag line.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XVIII—CAPACITANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTORS

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

CAPACITANCE C TO NEUTRAL IN MICROFARADS PER MILE OF EACH CONDUCTOR OF A SINGLE PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE CAPACITANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES

Size of Conductor: Circular Mils (Aluminum)	Size of Conductor: American Wire Gauge (B&S)	Number of Wires: Aluminum	Number of Wires: Steel	Outside Diameter in Inches	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin. 61%	Distance D between centers of conductors ★: 2 inches	4 inches	6 inches	8 inches	10 inches	12 inches	15 inches	18 inches	21 inches	24 inches	27 inches	30 inches	33 inches	36 inches
1 590 000		54	7	1.544	1 000 000	.119	.0557	.0440	.0384	.0350	.0326	.0302	.0284	.0271	.0260	.0252	.0244	.0238	.0233
1 510 500		54	7	1.506	950 000	.113	.0548	.0434	.0380	.0346	.0323	.0299	.0282	.0269	.0258	.0250	.0243	.0237	.0231
1 431 000		54	7	1.465	900 000	.108	.0538	.0428	.0376	.0343	.0320	.0296	.0279	.0267	.0256	.0248	.0241	.0235	.0230
1 351 500		54	7	1.424	850 000	.103	.0528	.0422	.0371	.0339	.0317	.0294	.0277	.0264	.0254	.0246	.0239	.0233	.0228
1 272 000		54	7	1.382	800 000	.0979	.0518	.0416	.0366	.0335	.0314	.0291	.0274	.0262	.0252	.0244	.0237	.0231	.0226
1 192 500		54	7	1.337	750 000	.0933	.0508	.0410	.0361	.0331	.0310	.0288	.0272	.0259	.0250	.0242	.0235	.0229	.0224
1 113 000		54	7	1.292	700 000	.0890	.0498	.0403	.0356	.0327	.0306	.0284	.0269	.0257	.0247	.0240	.0233	.0227	.0222
1 033 500		54	7	1.246	650 000	.0851	.0487	.0397	.0351	.0322	.0302	.0281	.0266	.0254	.0245	.0237	.0231	.0225	.0220
954 000		54	7	1.196	600 000	.0811	.0476	.0389	.0346	.0318	.0298	.0278	.0263	.0251	.0242	.0235	.0228	.0223	.0218
900 000		54	7	1.162	566 000	.0785	.0469	.0384	.0342	.0315	.0296	.0275	.0260	.0249	.0240	.0233	.0227	.0221	.0217
874 500		54	7	1.146	550 000	.0774	.0465	.0382	.0340	.0313	.0294	.0274	.0259	.0248	.0239	.0232	.0226	.0221	.0216
795 000		54	7	1.023	500 000	.0737	.0454	.0374	.0334	.0308	.0290	.0270	.0256	.0245	.0236	.0229	.0223	.0218	.0213
715 500		54	7	1.036	450 000	.0701	.0441	.0366	.0327	.0302	.0285	.0266	.0252	.0242	.0233	.0226	.0220	.0215	.0211
666 600		54	7	1.000	419 000	.0679	.0433	.0361	.0323	.0299	.0281	.0263	.0250	.0239	.0231	.0224	.0218	.0213	.0209
636 000		54	7	.977	400 000	.0665	.0428	.0357	.0320	.0296	.0279	.0261	.0248	.0238	.0230	.0223	.0217	.0212	.0208
605 000		54	7	.953	380 500	.0652	.0423	.0354	.0317	.0294	.0277	.0259	.0246	.0236	.0228	.0221	.0216	.0211	.0207
556 500		30	7	.953	350 000	.0652	.0423	.0354	.0317	.0294	.0277	.0259	.0246	.0236	.0228	.0221	.0216	.0211	.0207
556 500		26	7	.912	350 000	.0629	.0414	.0348	.0312	.0290	.0274	.0256	.0243	.0234	.0226	.0219	.0214	.0209	.0205
518 000		42	19	1.000	326 000	.0679	.0433	.0361	.0323	.0299	.0281	.0263	.0250	.0239	.0231	.0224	.0218	.0213	.0209
500 000		30	7	.904	314 500	.0624	.0412	.0346	.0311	.0289	.0273	.0255	.0243	.0233	.0225	.0219	.0213	.0208	.0204
477 000		30	7	.883	300 000	.0613	.0408	.0343	.0309	.0287	.0271	.0254	.0241	.0232	.0224	.0217	.0212	.0207	.0203
477 000		26	7	.845	300 000	.0593	.0400	.0338	.0304	.0283	.0267	.0251	.0238	.0229	.0221	.0215	.0210	.0205	.0201
397 500		30	7	.806	250 000	.0574	.0391	.0332	.0299	.0279	.0264	.0247	.0235	.0226	.0219	.0213	.0207	.0203	.0199
397 500		26	7	.771	250 000	.0556	.0384	.0326	.0295	.0275	.0260	.0244	.0233	.0224	.0216	.0210	.0205	.0201	.0197
336 400		30	7	.741	0 000	.0542	.0377	.0322	.0291	.0271	.0257	.0242	.0230	.0221	.0214	.0208	.0203	.0199	.0195
336 400		26	7	.710	0 000	.0527	.0370	.0317	.0287	.0268	.0254	.0239	.0228	.0219	.0212	.0206	.0201	.0197	.0194
300 000		30	7	.700	188 800	.0523	.0368	.0315	.0286	.0267	.0253	.0238	.0227	.0218	.0211	.0206	.0201	.0197	.0193
300 000		26	7	.670	188 800	.0509	.0362	.0310	.0282	.0263	.0250	.0235	.0224	.0216	.0209	.0204	.0199	.0195	.0191
266 800		26	7	.632	000	.0491	.0353	.0304	.0277	.0259	.0246	.0232	.0221	.0213	.0206	.0201	.0196	.0192	.0189
266 800		6	7	.633	000	.0492	.0353	.0304	.0277	.0259	.0246	.0232	.0221	.0213	.0207	.0201	.0196	.0192	0189
211 600	0 000	6	1	.564	00	.0461	.0338	.0293	.0267	.0251	.0238	.0225	.0215	.0207	0201	.0196	.0192	.0188	.0184
167 806	000	6	1	.501	0	.0434	.0323	.0282	.0258	.0243	.0231	.0219	.0209	.0202	.0196	.0191	.0187	.0183	.0180
133 077	00	6	1	.447	1	.0410	.0310	.0272	.0250	.0235	.0224	.0213	.0204	.0197	.0191	.0186	.0182	.0179	.0176
105 535	0	6	1	.398	2	.0389	.0298	.0263	.0242	.0228	.0218	.0207	.0198	.0192	.0187	.0182	.0178	.0175	0172
83 693	1	6	1	.355	3	.0370	.0287	.0254	.0235	.0222	.0212	.0201	.0193	.0187	.0182	.0178	.0174	.0171	.0168
66 371	2	6	1	.316	4	.0353	.0277	.0246	.0228	.0215	.0206	.0196	.0189	.0183	.0178	.0174	.0170	.0167	.0165
52 635	3	6	1	.281	5	.0337	.0267	.0238	.0221	.0210	.0201	.0191	.0184	.0179	.0174	.0170	.0167	.0164	.0161
41 741	4	6	1	.250	6	.0323	.0258	.0231	.0215	.0204	.0196	.0187	.0180	.0175	.0170	.0166	.0163	.0160	.0158
33 102	5	6	1	.223	7	.0310	.0250	.0224	.0209	.0199	.0191	.0182	.0176	.0171	.0166	.0163	.0160	.0157	.0155
26 2[illegible]1	6	6	1	.198	8	.0298	.0242	.0218	.0204	.0194	.0186	.0178	.0172	.0167	.0163	.0159	.0157	.0154	.0152

Circular Mils (Aluminum)	American Wire Gauge (B&S)	Aluminum	Steel	Distance D between centers of conductors ★: 3.5 feet (1.07 m)	4 feet (1.22 m)	5 feet (1.52 m)	6 feet (1.83 m)	7 feet (2.13 m)	8 feet (2.44 m)	9 feet (2.74 m)	11 feet (3.35 m)	13 feet (3.96 m)	15 feet (4.57 m)	17 feet (5.18 m)	19 feet (5.79 m)	21 feet (6.40 m)	23 feet (7.01 m)	25 feet (7.62 m)	30 feet (9.14 m)	35 feet (10.67 m)
1 590 000		54	7	.0224	.0216	.0205	.0197	.0191	.0185	.0181	.0174	.0168	.0164	.0160	.0157	.0154	.0152	.0150	.0146	.0142
1 510 500		54	7	.0222	.0215	.0204	.0196	.0190	.0184	.0180	.0173	.0168	.0163	.0160	.0156	.0154	.0151	.0149	.0145	.0141
1 431 000		54	7	.0221	.0214	.0203	.0195	.0189	.0183	.0179	.0172	.0167	.0162	.0159	.0156	.0153	.0151	.0149	.0144	.0141
1 351 500		54	7	.0219	.0212	.0202	.0194	.0187	.0182	.0178	.0171	.0166	.0162	.0158	.0155	.0152	.0150	.0148	.0144	.0140
1 272 000		54	7	.0218	.0211	.0200	.0192	.0186	.0181	.0177	.0170	.0165	.0161	.0157	.0154	.0152	.0149	.0147	.0143	.0139
1 192 500		54	7	.0216	.0209	.0199	.0191	.0185	.0180	.0176	.0169	.0164	.0160	.0156	.0153	.0151	.0148	.0146	.0142	.0139
1 113 000		54	7	.0214	.0208	.0197	.0190	.0184	.0179	.0175	.0168	.0163	.0159	.0155	.0152	.0150	.0148	.0146	.0141	.01[illegible]
1 033 500		54	7	.0212	.0206	.0196	.0188	.0182	.0177	.0173	.0167	.0162	.0158	.0154	.0151	.0149	.0147	.0145	.0141	.0137
954 000			7	.0210	.0204	.0194	.0187	.0181	.0176	.0172	.0166	.0161	.0157	.0153	.0150	.0148	.0146	.0144	.0140	.0136
900 000		54	7	.0209	.0203	.0193	.0186	.0180	.0175	.0171	.0165	.0160	.0156	.0153	.0150	.0147	.0145	.0143	.0139	.0136
874 500		54	7	.0208	.0202	.0192	.0185	.0179	.0175	.0171	.0164	.0159	.0155	.0152	.0149	.0147	.0145	.0143	.0139	.0136
795 000		54	7	.0206	.0200	.0190	.0183	.0178	.0173	.0169	.0163	.0158	.0154	.0151	.0148	.0146	.0144	.0142	.0138	.0135
715 500		54	7	.0203	.0197	.0188	.0181	.0176	.0171	.0167	.0161	.0157	.0153	.0150	.0147	.0145	.0142	.0141	.0137	.0133
666 600		54	7	.0202	.0196	.0187	.0180	.0174	.0170	.0166	.0160	.0156	.0152	.0149	.0146	.0144	.0142	.0140	.0136	.0133
636 000		54	7	.0201	.0195	.0186	.0179	.0174	.0169	.0166	.0160	.0155	.0151	.0148	.0145	.0143	.0141	.0139	.0135	.0132
605 000		54	7	.0200	.0194	.0185	.0178	.0173	.0169	.0165	.0159	.0154	.0151	.0148	.0145	.0143	.0141	.0139	.0135	.0132
556 500		30	7	.0200	.0194	.0185	.0178	.0173	.0169	.0165	.0159	.0154	.0151	.0148	.0145	.0143	.0141	.0139	.0135	.0132
556 500		26	7	.0198	.0192	.0183	.0177	.0171	.0167	.0164	.0158	.0153	.0150	.0147	.0144	.0142	.0140	.0138	.0134	.0131
518 000		42	19	.0202	.0196	.0187	.0180	.0174	.0170	.0166	.0160	.0156	.0152	.0149	.0146	.0144	.0142	.0140	.0136	.0133
500 000		30	7	.0197	.0192	.0183	.0176	.0171	.0167	.0163	.0157	.0153	.0149	.0146	.0144	.0141	.0139	.0138	.0134	.0131
477 000		30	7	.0196	.0191	.0182	.0175	.0170	.0166	.0163	.0157	.0152	.0149	.0146	.0143	.0141	.0139	.0137	.0133	.0130
477 000		26	7	.0194	.0189	.0180	.0174	.0169	.0165	.0161	.0156	.0151	.0148	.0145	.0142	.0140	.0138	.0136	.0132	.0130
397 500		30	7	.0192	.0187	.0179	.0172	.0167	.0163	.0160	.0154	.0150	.0147	.0144	.0141	.0139	.0137	.0135	.0132	.0129
397 500		26	7	.0191	.0185	.0177	.0171	.0166	.0162	.0159	.0153	.0149	.0145	.0143	.0140	.0138	.0136	.0134	.0131	.0128
336 400		30	7	.0189	.0184	.0176	.0170	.0165	.0161	.0158	.0152	.0148	.0145	.0142	.0139	.0137	.0135	.0134	.0130	.0127
336 400		26	7	.0187	.0182	.0174	.0168	.0164	.0160	.0156	.0151	.0147	.0144	.0141	.0138	.0136	.0134	.0133	.0129	.0126
300 000		30	7	.0187	.0182	.0174	.0168	.0163	.0159	.0156	.0151	.0147	.0143	.0140	.0138	.0136	.0134	.0132	.0129	.0126
300 000		26	7	.0185	.0180	.0172	.0166	.0162	.0158	.0155	.0150	.0146	.0142	.0139	.0137	.0135	.0133	.0132	.0128	.0125
266 800		26	7	.0183	.0178	.0170	.0165	.0160	.0156	.0153	.0148	.0144	.0141	.0138	.0136	.0134	.0132	.0130	.0127	.0124
266 800		6	7	.0183	.0178	.0170	.0165	.0160	.0156	.0153	.0148	.0144	.0141	.0138	.0136	.0134	.0132	.0130	.0127	.0124
211 600	0000	6	1	.0179	.0174	.0167	.0161	.0157	.0153	.0150	.0145	.0142	.0138	.0136	.0134	.0132	.0130	.0128	.0125	.0122
167 806	000	6	1	.0175	.0170	.0163	.0158	.0154	.0150	.0147	.0143	.0139	.0136	.0133	.0131	.0129	.0128	.0126	.0123	.0120
133 077	00	6	1	.0171	.0166	.0160	.0155	.0151	.0147	.0145	.0140	.0137	.0134	.0131	.0129	.0127	.0126	.0124	.0121	.0119
105 535	0	6	1	.0167	.0163	.0157	.0152	.0148	.0145	.0142	.0138	.0134	.0131	.0129	.0127	.0125	.0124	.0122	.0119	.0117
83 693	1	6	1	.0164	.0160	.0153	.0149	.0145	.0142	.0139	.0135	.0132	.0129	.0127	.0125	.0123	.0122	.0120	.0117	.0115
66 371	2	6	1	.0160	.0156	.0150	.0146	.0142	.0139	.0137	.0133	.0130	.0127	.0125	.0123	.0121	.0120	.0118	.0116	.0113
52 635	3	6	1	.0157	.0153	.0148	.0143	.0140	.0137	.0135	.0131	.0128	.0125	.0123	.0121	.0119	.0118	.0117	.0114	.0112
41 741	4	6	1	.0154	.0150	.0145	.0141	.0137	.0135	.0132	.0128	.0125	.0123	.0121	.0119	.0118	.0116	.0115	.0112	.0110
33 102	5	6	1	.0151	.0147	.0142	.0138	.0135	.0132	.0130	.0126	.0123	.0121	.0119	.0117	.0116	.0114	.0113	.0111	.0109
26 251	6	6	1	.0148	.0145	.0140	.0136	.0133	.0130	.0128	.0124	.0121	.0119	.0117	.0116	.0114	.0113	.0112	.0109	.0107

The table values are derived from the exact equation $C = \dfrac{0.038829}{\log_{10}\left(\dfrac{D}{d} + \sqrt{\left(\dfrac{D}{d}\right)^2 - 1}\right)}$ d being the diameter of the conductor expressed in the same units as D.

When D is large compared with d as is always the case in high-tension transmission lines employing bare conductors, the capacitance may be calculated, with negligible error, from the simplified equation $C = \dfrac{0.038829}{\log_{10} \dfrac{2D}{d}}$

The heavy zig-zag line shows the points at which the exact and simplified equations give the same result to the three significant figures of the table, the exact equation having been used in that portion of the table above and to the left of the zig-zag line and the simplified equation in that portion below and to the right of the zig-zag line.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XIX—25 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

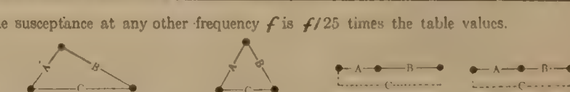
25 CYCLE CAPACITY SUSCEPTANCE b TO NEUTRAL IN MICROMHOS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES.

SIZE OF CONDUCTOR		NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S			2 INCHES (5.1 CM.)	4 INCHES (10.2 CM.)	6 INCHES (15.2 CM.)	8 INCHES (20.3 CM.)	10 INCHES (25.4 CM.)	12 INCHES (30.5 CM.)	15 INCHES (38.1 CM.)	18 INCHES (45.7 CM.)	21 INCHES (53.3 CM.)	24 INCHES (61.0 CM.)	27 INCHES (68.6 CM.)	30 INCHES (76.2 CM.)	33 INCHES (83.8 CM.)	36 INCHES (91.4 CM.)
2000000		127	1.631	21.3	9.09	7.11	6.18	5.62	5.23	4.83	4.54	4.33	4.15	4.01	3.90	3.80	3.71
1900000		127	1.590	20.0	8.92	7.01	6.11	5.56	5.18	4.79	4.50	4.29	4.12	3.99	3.87	3.77	3.68
1800000		127	1.548	18.8	8.76	6.91	6.04	5.50	5.13	4.74	4.47	4.26	4.09	3.95	3.84	3.74	3.66
1700000		127	1.504	17.7	8.60	6.82	5.96	5.44	5.08	4.70	4.43	4.22	4.06	3.92	3.81	3.71	3.63
1600000		127	1.459	16.8	8.43	6.71	5.89	5.38	5.02	4.65	4.38	4.18	4.02	3.89	3.78	3.68	3.60
1500000		91	1.412	15.9	8.25	6.61	5.80	5.31	4.96	4.60	4.34	4.14	3.98	3.86	3.75	3.65	3.57
1400000		91	1.364	15.1	8.08	6.50	5.72	5.24	4.90	4.55	4.29	4.10	3.95	3.82	3.71	3.62	3.54
1300000		91	1.315	14.3	7.90	6.39	5.64	5.17	4.84	4.49	4.24	4.06	3.90	3.78	3.68	3.59	3.51
1200000		91	1.263	13.6	7.72	6.27	5.55	5.09	4.77	4.44	4.19	4.01	3.86	3.74	3.64	3.55	3.47
1100000		91	1.209	12.9	7.53	6.15	5.45	5.01	4.70	4.38	4.14	3.96	3.82	3.70	3.60	3.51	3.44
1000000		61	1.152	12.2	7.33	6.02	5.35	4.93	4.63	4.31	4.08	3.91	3.77	3.65	3.55	3.47	3.40
950000		61	1.123	11.9	7.23	5.95	5.30	4.88	4.59	4.28	4.05	3.88	3.74	3.63	3.53	3.45	3.38
900000		61	1.093	11.6	7.13	5.88	5.24	4.84	4.55	4.24	4.02	3.85	3.71	3.60	3.51	3.43	3.35
850000		61	1.062	11.3	7.02	5.81	5.19	4.79	4.51	4.21	3.99	3.82	3.69	3.58	3.48	3.40	3.33
800000		61	1.031	11.0	6.91	5.74	5.13	4.74	4.46	4.17	3.95	3.79	3.66	3.55	3.46	3.38	3.31
750000		61	.998	10.6	6.80	5.66	5.07	4.69	4.42	4.13	3.92	3.76	3.63	3.52	3.43	3.35	3.28
700000		61	.964	10.3	6.68	5.58	5.01	4.64	4.37	4.09	3.88	3.72	3.59	3.49	3.40	3.32	3.26
650000		61	.929	10.0	6.56	5.50	4.94	4.58	4.32	4.05	3.84	3.69	3.56	3.46	3.37	3.29	3.23
600000		37	.891	9.70	6.44	5.41	4.87	4.52	4.27	4.00	3.80	3.65	3.52	3.42	3.34	3.26	3.20
550000		37	.853	9.39	6.31	5.32	4.80	4.46	4.21	3.95	3.75	3.61	3.49	3.39	3.30	3.23	3.17
500000		37	.814	9.07	6.17	5.23	4.72	4.39	4.15	3.90	3.71	3.56	3.44	3.35	3.27	3.19	3.13
450000		37	.772	8.75	6.03	5.13	4.64	4.32	4.09	3.84	3.66	3.51	3.40	3.31	3.23	3.16	3.10
400000		19	.725	8.40	5.87	5.01	4.54	4.24	4.01	3.77	3.60	3.46	3.35	3.26	3.18	3.11	3.05
350000		19	.679	8.05	5.71	4.89	4.45	4.15	3.94	3.71	3.54	3.40	3.30	3.21	3.13	3.07	3.01
300000		19	.628	7.69	5.53	4.77	4.34	4.06	3.86	3.63	3.47	3.34	3.24	3.15	3.08	3.02	2.96
250000		19	.574	7.31	5.34	4.62	4.22	3.96	3.76	3.55	3.39	3.27	3.17	3.09	3.02	2.96	2.91
211600	0000	7	.522	6.95	5.15	4.48	4.10	3.85	3.67	3.47	3.32	3.20	3.11	3.03	2.96	2.90	2.85
167806	000	7	.464	6.56	4.95	4.32	3.97	3.73	3.56	3.37	3.23	3.12	3.03	2.95	2.89	2.83	2.78
133077	00	7	.414	6.22	4.75	4.17	3.84	3.62	3.46	3.28	3.14	3.04	2.95	2.88	2.82	2.77	2.72
105535	0	7	.368	5.91	4.57	4.03	3.72	3.52	3.36	3.19	3.06	2.97	2.88	2.82	2.76	2.71	2.66
83693	1	7	.328	5.63	4.40	3.90	3.61	3.42	3.27	3.11	2.99	2.89	2.82	2.75	2.70	2.65	2.61
66371	2	7	.292	5.38	4.24	3.78	3.51	3.32	3.19	3.03	2.92	2.83	2.75	2.69	2.64	2.59	2.55
52635	3	7	.260	5.15	4.10	3.67	3.41	3.23	3.10	2.96	2.85	2.76	2.69	2.63	2.58	2.54	2.50
41741	4	7	.232	4.94	3.97	3.56	3.32	3.15	3.03	2.89	2.78	2.70	2.63	2.58	2.53	2.48	2.45
33102	5	7	.206	4.74	3.84	3.46	3.23	3.07	2.95	2.82	2.72	2.64	2.58	2.52	2.48	2.43	2.40
26251	6	7	.184	4.56	3.72	3.36	3.14	2.99	2.88	2.76	2.66	2.59	2.52	2.47	2.43	2.39	2.35

CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	[illegible] FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)	9 FEET (2.74 M.)	11 FEET (3.35 M.)	13 FEET (3.96 M.)	15 FEET (4.57 M.)	17 FEET (5.18 M.)	19 FEET (5.79 M.)	21 FEET (6.40 M.)	23 FEET (7.01 M.)	[illegible] FEET (7.62 M.)	30 FEET (9.14 M.)	35 FEET (10.67 M.)
2000000		3.56	3.45	3.27	3.13	3.03	2.95	2.87	2.76	2.67	2.60	2.54	2.49	2.45	2.41	2.38	2.31	2.25
1900000		3.54	3.43	3.25	3.12	3.01	2.93	2.86	2.75	2.66	2.59	2.53	2.48	2.44	2.40	2.37	2.30	2.24
1800000		3.52	3.40	3.23	3.10	3.00	2.91	2.84	2.73	2.65	2.58	2.52	2.47	2.43	2.39	2.36	2.29	2.23
1700000		3.49	3.38	3.21	3.08	2.98	2.90	2.83	2.72	2.63	2.56	2.51	2.46	2.42	2.38	2.35	2.28	2.22
1600000		3.47	3.35	3.18	3.06	2.96	2.88	2.81	2.70	2.62	2.55	2.49	2.44	2.40	2.37	2.33	2.26	2.21
1500000		3.44	3.33	3.16	3.04	2.94	2.86	2.79	2.69	2.60	2.53	2.48	2.43	2.39	2.35	2.32	2.25	2.20
1400000		3.41	3.30	3.14	3.01	2.92	2.84	2.77	2.67	2.59	2.52	2.46	2.42	2.38	2.34	2.31	2.24	2.19
1300000		3.38	3.27	3.11	2.99	2.90	2.82	2.75	2.65	2.57	2.50	2.45	2.40	2.36	2.33	2.29	2.23	2.17
1200000		3.35	3.24	3.08	2.97	2.87	2.80	2.73	2.63	2.55	2.48	2.43	2.38	2.35	2.31	2.28	2.21	2.16
1100000		3.31	3.21	3.05	2.94	2.85	2.77	2.71	2.61	2.53	2.47	2.41	2.37	2.33	2.29	2.26	2.20	2.15
1000000		3.27	3.18	3.02	2.91	2.82	2.75	2.68	2.58	2.51	2.44	2.39	2.35	2.31	2.28	2.25	2.18	2.13
950000		3.26	3.16	3.01	2.89	2.80	2.73	2.67	2.57	2.50	2.43	2.38	2.34	2.30	2.27	2.24	2.17	2.12
900000		3.23	3.14	2.99	2.88	2.79	2.72	2.66	2.56	2.48	2.42	2.37	2.33	2.29	2.26	2.23	2.16	2.11
850000		3.21	3.12	2.97	2.86	2.77	2.70	2.64	2.55	2.47	2.41	2.36	2.32	2.28	2.25	2.22	2.15	2.10
800000		3.19	3.10	2.95	2.84	2.76	2.69	2.63	2.53	2.46	2.40	2.35	2.31	2.27	2.24	2.21	2.14	2.10
750000		3.17	3.08	2.93	2.82	2.74	2.67	2.61	2.52	2.44	2.39	2.34	2.29	2.26	2.22	2.19	2.13	2.09
700000		3.14	3.05	2.91	2.81	2.72	2.65	2.60	2.50	2.43	2.37	2.32	2.28	2.24	2.21	2.18	2.12	2.07
650000		3.12	3.03	2.89	2.78	2.70	2.63	2.58	2.49	2.41	2.36	2.31	2.27	2.23	2.20	2.17	2.11	2.06
600000		3.09	3.00	2.86	2.76	2.68	2.61	2.56	2.47	2.40	2.34	2.29	2.25	2.22	2.18	2.16	2.10	2.05
550000		3.06	2.97	2.84	2.74	2.66	2.59	2.54	2.45	2.38	2.32	2.28	2.24	2.20	2.17	2.14	2.08	2.04
500000		3.03	2.94	2.81	2.71	2.63	2.57	2.52	2.43	2.36	2.31	2.26	2.22	2.18	2.15	2.13	2.07	2.02
450000		2.99	2.91	2.78	2.69	2.61	2.55	2.49	2.41	2.34	2.29	2.24	2.20	2.17	2.14	2.11	2.05	2.01
400000		2.96	2.87	2.75	2.65	2.58	2.52	2.47	2.38	2.32	2.26	2.22	2.18	2.15	2.12	2.09	2.04	1.99
350000		2.91	2.84	2.71	2.62	2.55	2.49	2.44	2.35	2.29	2.24	2.19	2.16	2.12	2.10	2.07	2.02	1.97
300000		2.87	2.79	2.67	2.58	2.51	2.45	2.40	2.32	2.26	2.21	2.17	2.13	2.10	2.07	2.05	1.99	1.95
250000		2.82	2.74	2.63	2.54	2.47	2.42	2.37	2.29	2.23	2.18	2.14	2.10	2.07	2.04	2.02	1.97	1.93
211600	0000	2.76	2.69	2.58	2.50	2.43	2.38	2.33	2.26	2.20	2.15	2.11	2.07	2.04	2.02	1.99	1.94	1.90
167806	000	2.70	2.63	2.53	2.45	2.38	2.33	2.29	2.21	2.16	2.11	2.07	2.04	2.01	1.98	1.96	1.91	1.87
133077	00	2.64	2.58	2.48	2.40	2.34	2.29	2.24	2.17	2.12	2.07	2.04	2.00	1.98	1.95	1.93	1.88	1.84
105535	0	2.59	2.52	2.43	2.35	2.29	2.24	2.20	2.14	2.08	2.04	2.00	1.97	1.94	1.92	1.90	1.85	1.82
83693	1	2.53	2.47	2.38	2.31	2.25	2.20	2.16	2.10	2.05	2.01	1.97	1.94	1.91	1.89	1.87	1.83	1.79
66371	2	2.48	2.42	2.33	2.27	2.21	2.16	2.13	2.06	2.01	1.97	1.94	1.91	1.88	1.86	1.84	1.80	1.76
52635	3	2.43	2.38	2.29	2.22	2.17	2.13	2.09	2.03	1.98	1.94	1.91	1.88	1.86	1.83	1.81	1.77	1.74
41741	4	2.38	2.33	2.25	2.18	2.13	2.09	2.05	2.00	1.95	1.91	1.88	1.85	1.83	1.81	1.79	1.75	1.71
33102	5	2.34	2.29	2.21	2.14	2.10	2.05	2.02	1.96	1.92	1.88	1.85	1.82	1.80	1.78	1.76	1.72	1.69
26251	6	2.29	2.24	2.17	2.11	2.06	2.02	1.99	1.93	1.89	1.85	1.82	1.80	1.77	1.75	1.74	1.70	1.67

The values for susceptance were derived from the equation $b = 2\pi f C$. The susceptance at any other frequency f is $f/25$ times the table values.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B or C for symmetrical triangular spacing and into $D = 1.26\,A$ or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

The charging current in amperes per mile of single conductor to neutral equals the (susceptance from the table) × (volts to neutral) × 10^{-6}

TABLE XX—25 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

25 CYCLE CAPACITY SUSCEPTANCE b TO NEUTRAL IN MICROMHOS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES.

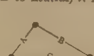
SIZE OF CONDUCTOR: CIRCULAR MILS (ALUMINUM)	SIZE OF CONDUCTOR: AMERICAN WIRE GAUGE B&S	NUMBER OF WIRES: ALUMINUM	NUMBER OF WIRES: STEEL	OUTSIDE DIAMETER IN INCHES	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★ 2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
1 590 000		54	7	1.544	1 000 000	18.7	8.75	6.91	6.03	5.50	5.13	4.74	4.46	4.25	4.09	3.95	3.84	3.74	3.66
1 510 500		54	7	1.506	950 000	17.8	8.60	6.82	5.97	5.44	5.08	4.70	4.43	4.22	4.06	3.92	3.81	3.72	3.63
1 431 000		54	7	1.465	900 000	16.9	8.45	6.73	5.91	5.39	5.03	4.66	4.39	4.19	4.03	3.90	3.78	3.69	3.61
1 351 500		54	7	1.424	850 000	16.1	8.30	6.63	5.85	5.33	4.98	4.61	4.35	4.15	3.99	3.87	3.76	3.66	3.58
1 272 000		54	7	1.382	800 000	15.4	8.14	6.54	5.75	5.26	4.93	4.57	4.31	4.11	3.96	3.83	3.73	3.63	3.55
1 192 500		54	7	1.337	750 000	14.7	7.98	6.44	5.68	5.20	4.87	4.52	4.27	4.08	3.92	3.80	3.69	3.60	3.52
1 113 000		54	7	1.292	700 000	14.0	7.82	6.34	5.60	5.14	4.81	4.47	4.22	4.04	3.89	3.76	3.66	3.57	3.49
1 033 500		54	7	1.246	650 000	13.4	7.66	6.23	5.52	5.07	4.75	4.42	4.18	3.99	3.85	3.73	3.63	3.54	3.46
954 000		54	7	1.196	600 000	12.7	7.48	6.12	5.43	4.99	4.69	4.36	4.13	3.95	3.81	3.69	3.59	3.50	3.43
900 000		54	7	1.162	566 000	12.3	7.36	6.04	5.37	4.94	4.64	4.32	4.09	3.92	3.78	3.66	3.56	3.48	3.40
874 500		54	7	1.146	550 000	12.2	7.31	6.00	5.34	4.92	4.62	4.30	4.08	3.90	3.76	3.65	3.55	3.46	3.39
795 000		54	7	1.093	500 000	11.6	7.12	5.88	5.24	4.84	4.55	4.24	4.02	3.85	3.71	3.60	3.51	3.43	3.35
715 500		54	7	1.036	450 000	11.0	6.93	5.75	5.14	4.75	4.47	4.17	3.96	3.79	3.66	3.55	3.46	3.38	3.31
666 600		54	7	1.000	419 000	10.7	6.81	5.67	5.07	4.69	4.42	4.13	3.92	3.76	3.63	3.52	3.43	3.35	3.28
636 000		54	7	.977	400 000	10.5	6.73	5.62	5.03	4.66	4.39	4.10	3.90	3.73	3.61	3.50	3.41	3.33	3.27
605 000		54	7	.953	380 500	10.2	6.65	5.56	4.99	4.62	4.36	4.07	3.87	3.71	3.58	3.48	3.39	3.32	3.25
556 500		30	7	.953	350 000	10.2	6.65	5.56	4.99	4.62	4.36	4.07	3.87	3.71	3.58	3.48	3.39	3.32	3.25
556 500		26	7	.912	350 000	9.88	6.51	5.46	4.91	4.55	4.30	4.02	3.82	3.67	3.54	3.44	3.36	3.28	3.22
518 000		42	19	1.000	326 000	10.7	6.81	5.67	5.07	4.69	4.42	4.13	3.92	3.76	3.63	3.52	3.43	3.35	3.28
500 000		30	7	.904	314 500	9.81	6.48	5.44	4.89	4.54	4.29	4.01	3.81	3.66	3.54	3.43	3.35	3.27	3.21
477 000		30	7	.883	300 000	9.63	6.41	5.39	4.85	4.50	4.25	3.98	3.79	3.64	3.51	3.41	3.33	3.26	3.19
477 000		26	7	.845	300 000	9.32	6.28	5.30	4.78	4.44	4.20	3.94	3.74	3.60	3.48	3.38	3.29	3.22	3.16
397 500		30	7	.806	250 000	9.01	6.15	5.21	4.70	4.38	4.14	3.88	3.70	3.55	3.44	3.34	3.26	3.19	3.13
397 500		26	7	.771	250 000	8.74	6.03	5.13	4.64	4.32	4.09	3.84	3.66	3.51	3.40	3.31	3.23	3.16	3.10
336 400		30	7	.741	0000	8.52	5.93	5.05	4.58	4.26	4.04	3.80	3.62	3.48	3.37	3.28	3.20	3.13	3.07
336 400		26	7	.710	0000	8.28	5.82	4.97	4.51	4.21	3.99	3.75	3.58	3.44	3.33	3.24	3.17	3.10	3.04
300 000		30	7	.700	188 800	8.21	5.78	4.95	4.49	4.19	3.98	3.74	3.57	3.43	3.32	3.23	3.16	3.09	3.03
300 000		26	7	.670	188 800	7.99	5.68	4.87	4.43	4.14	3.93	3.70	3.53	3.39	3.29	3.20	3.13	3.06	3.00
266 800		26	7	.632	000	7.72	5.55	4.78	4.35	4.07	3.86	3.64	3.48	3.35	3.24	3.16	3.05	3.02	2.97
266 800		6	7	.633	000	7.73	5.55	4.78	4.35	4.07	3.86	3.64	3.48	3.35	3.24	3.16	3.05	3.02	2.97
211 600	0000	6	1	.564	00	7.25	5.31	4.60	4.20	3.94	3.74	3.53	3.38	3.26	3.16	3.08	3.01	2.95	2.90
167 806	000	6	1	.501	0	6.81	5.08	4.43	4.06	3.81	3.63	3.43	3.29	3.17	3.08	3.00	2.94	2.88	2.83
133 077	00	6	1	.447	1	6.45	4.87	4.27	3.93	3.70	3.53	3.34	3.20	3.09	3.00	2.93	2.87	2.81	2.76
105 535	0	6	1	.398	2	6.11	4.69	4.12	3.80	3.59	3.43	3.25	3.12	3.02	2.93	2.86	2.80	2.75	2.70
83 693	1	6	1	.355	3	5.82	4.51	3.99	3.69	3.48	3.33	3.16	3.04	2.94	2.86	2.80	2.74	2.69	2.64
66 371	2	6	1	.316	4	5.54	4.35	3.86	3.58	3.39	3.24	3.08	2.96	2.87	2.80	2.73	2.68	2.63	2.59
52 635	3	6	1	.281	5	5.30	4.20	3.74	3.48	3.29	3.16	3.01	2.89	2.81	2.73	2.67	2.62	2.57	2.53
41 741	4	6	1	.250	6	5.07	4.06	3.63	3.38	3.21	3.08	2.94	2.83	2.74	2.67	2.61	2.56	2.52	2.48
33 102	5	6	1	.223	7	4.87	3.92	3.52	3.29	3.12	3.00	2.87	2.76	2.68	2.61	2.56	2.51	2.47	2.43
26 251	6	6	1	.198	8	4.68	3.80	3.43	3.20	3.05	2.93	2.80	2.70	2.62	2.56	2.51	2.46	2.42	2.38

CIRCULAR MILS (ALUMINUM)	AMERICAN WIRE GAUGE B&S	ALUMINUM	STEEL	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★ 3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
1 590 000		54	7	3.51	3.40	3.23	3.10	3.00	2.91	2.84	2.73	2.65	2.58	2.52	2.47	2.43	2.39	2.36	2.29	2.23
1 510 500		54	7	3.49	3.38	3.21	3.08	2.98	2.90	2.83	2.72	2.63	2.56	2.51	2.46	2.42	2.38	2.35	2.28	2.22
1 431 000		54	7	3.47	3.36	3.19	3.06	2.96	2.88	2.81	2.70	2.62	2.55	2.50	2.45	2.41	2.37	2.34	2.27	2.21
1 351 500		54	7	3.45	3.34	3.17	3.04	2.94	2.86	2.80	2.69	2.61	2.54	2.48	2.44	2.39	2.36	2.32	2.26	2.20
1 272 000		54	7	3.42	3.31	3.15	3.02	2.93	2.85	2.78	2.67	2.59	2.53	2.47	2.42	2.38	2.35	2.31	2.25	2.19
1 192 500		54	7	3.39	3.29	3.12	3.00	2.91	2.83	2.76	2.66	2.58	2.51	2.46	2.41	2.37	2.33	2.30	2.23	2.18
1 113 000		54	7	3.37	3.26	3.10	2.98	2.89	2.81	2.75	2.64	2.56	2.50	2.44	2.39	2.36	2.32	2.29	2.22	2.17
1 033 500		54	7	3.34	3.23	3.07	2.96	2.86	2.79	2.72	2.62	2.54	2.48	2.43	2.38	2.34	2.31	2.27	2.21	2.16
954 000			7	3.30	3.20	3.05	2.93	2.84	2.77	2.70	2.60	2.53	2.46	2.41	2.36	2.32	2.29	2.26	2.20	2.14
900 000		54	7	3.28	3.18	3.03	2.91	2.83	2.75	2.69	2.59	2.51	2.45	2.40	2.35	2.31	2.28	2.25	2.19	2.13
874 500		54	7	3.27	3.17	3.02	2.91	2.82	2.74	2.68	2.58	2.51	2.44	2.39	2.35	2.31	2.27	2.24	2.18	2.13
795 000		54	7	3.24	3.14	2.99	2.88	2.79	2.72	2.66	2.56	2.48	2.42	2.37	2.33	2.29	2.26	2.23	2.17	2.12
715 500		54	7	3.20	3.10	2.96	2.85	2.76	2.69	2.63	2.54	2.46	2.40	2.35	2.31	2.27	2.24	2.21	2.15	2.10
666 600		54	7	3.17	3.08	2.94	2.83	2.74	2.67	2.61	2.52	2.45	2.39	2.34	2.29	2.26	2.23	2.20	2.14	2.09
636 000		54	7	3.15	3.06	2.92	2.81	2.73	2.66	2.60	2.51	2.44	2.38	2.33	2.29	2.25	2.22	2.19	2.13	2.08
605 000		54	7	3.14	3.05	2.91	2.80	2.72	2.65	2.59	2.50	2.43	2.37	2.32	2.28	2.24	2.21	2.18	2.12	2.07
556 500		30	7	3.14	3.05	2.91	2.80	2.72	2.65	2.59	2.50	2.43	2.37	2.32	2.28	2.24	2.21	2.18	2.12	2.07
556 500		26	7	3.11	3.02	2.88	2.77	2.69	2.63	2.57	2.48	2.41	2.35	2.30	2.26	2.23	2.19	2.17	2.11	2.06
518 000		42	19	3.17	3.08	2.94	2.83	2.74	2.67	2.61	2.52	2.45	2.39	2.34	2.29	2.26	2.23	2.20	2.14	2.09
500 000		30	7	3.10	3.01	2.87	2.77	2.69	2.62	2.57	2.47	2.40	2.35	2.30	2.26	2.22	2.19	2.16	2.10	2.06
477 000		30	7	3.08	3.00	2.86	2.76	2.68	2.61	2.55	2.46	2.39	2.34	2.29	2.25	2.21	2.18	2.15	2.10	2.05
477 000		26	7	3.05	2.97	2.83	2.73	2.65	2.59	2.53	2.44	2.38	2.32	2.27	2.23	2.20	2.17	2.14	2.08	2.03
397 500		30	7	3.02	2.94	2.81	2.71	2.63	2.57	2.51	2.43	2.36	2.30	2.26	2.22	2.18	2.15	2.12	2.07	2.02
397 500		26	7	2.99	2.91	2.78	2.69	2.61	2.55	2.49	2.41	2.34	2.29	2.24	2.20	2.17	2.14	2.11	2.05	2.01
336 400		30	7	2.97	2.89	2.76	2.67	2.59	2.53	2.48	2.39	2.33	2.27	2.23	2.19	2.15	2.12	2.10	2.04	2.00
336 400		26	7	2.94	2.86	2.74	2.64	2.57	2.51	2.46	2.37	2.31	2.25	2.21	2.17	2.14	2.11	2.09	2.03	1.99
300 000		30	7	2.94	2.86	2.73	2.64	2.56	2.50	2.45	2.37	2.30	2.25	2.21	2.17	2.14	2.11	2.08	2.03	1.98
300 000		26	7	2.91	2.83	2.71	2.62	2.54	2.48	2.43	2.35	2.29	2.23	2.19	2.15	2.12	2.09	2.07	2.01	1.97
266 800		26	7	2.87	2.80	2.68	2.59	2.52	2.46	2.41	2.33	2.27	2.21	2.17	2.13	2.10	2.07	2.05	2.00	1.95
266 800		6	7	2.87	2.80	2.68	2.59	2.52	2.46	2.41	2.33	2.27	2.21	2.17	2.13	2.10	2.07	2.05	2.00	1.95
211 600	0000	6	1	2.81	2.73	2.62	2.53	2.47	2.41	2.36	2.28	2.22	2.17	2.13	2.10	2.07	2.04	2.02	1.96	1.92
167 806	000	6	1	2.74	2.67	2.56	2.48	2.42	2.36	2.32	2.24	2.18	2.14	2.10	2.06	2.03	2.01	1.98	1.93	1.89
133 077	00	6	1	2.68	2.62	2.51	2.43	2.37	2.32	2.27	2.20	2.14	2.10	2.06	2.03	2.00	1.97	1.95	1.90	1.86
105 535	0	6	1	2.62	2.56	2.46	2.39	2.32	2.27	2.23	2.16	2.11	2.06	2.03	1.99	1.97	1.94	1.92	1.87	1.84
83 693	1	6	1	2.57	2.51	2.41	2.34	2.28	2.23	2.19	2.12	2.07	2.03	1.99	1.96	1.94	1.91	1.89	1.84	1.81
66 371	2	6	1	2.52	2.46	2.36	2.29	2.24	2.19	2.15	2.09	2.04	2.00	1.96	1.93	1.90	1.88	1.86	1.82	1.78
52 635	3	6	1	2.47	2.41	2.32	2.25	2.20	2.15	2.12	2.05	2.00	1.96	1.93	1.90	1.87	1.85	1.83	1.79	1.76
41 741	4	6	1	2.42	2.36	2.28	2.21	2.16	2.12	2.08	2.02	1.97	1.93	1.90	1.87	1.85	1.82	1.81	1.76	1.73
33 102	5	6	1	2.37	2.32	2.23	2.17	2.12	2.08	2.04	1.98	1.94	1.90	1.87	1.84	1.82	1.80	1.78	1.74	1.71
26 251	6	6	1	2.32	2.27	2.19	2.13	2.08	2.04	2.01	1.95	1.91	1.87	1.84	1.82	1.79	1.77	1.75	1.71	1.68

The values for susceptance were derived from the equation $b = 2\pi f C$. The susceptance at any other frequency f is $f/25$ times the table values.

The charging current in amperes per mile of single conductor to neutral equals the (susceptance from the table) × (volts to neutral) × 10^{-6}

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing

Symmetrical triangular spacing

Irregular flat spacing

Regular flat spacing

TABLE XXI—60 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

60 CYCLE CAPACITY SUSCEPTANCE b TO NEUTRAL IN MICROMHOS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES.

SIZE OF CONDUCTOR: CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★													
				2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
2000000		127	1.631	51.1	21.8	17.1	14.8	13.5	12.6	11.6	10.9	10.4	9.97	9.63	9.35	9.11	8.90
1900000		127	1.590	47.9	21.4	16.8	14.7	13.3	12.4	11.5	10.8	10.3	9.89	9.56	9.29	9.05	8.84
1800000		127	1.548	45.1	21.0	16.6	14.5	13.2	12.3	11.4	10.7	10.2	9.82	9.49	9.22	8.98	8.78
1700000		127	1.504	42.6	20.6	16.4	14.3	13.1	12.2	11.3	10.6	10.1	9.74	9.41	9.15	8.91	8.71
1600000		127	1.459	40.3	20.2	16.1	14.1	12.9	12.1	11.2	10.5	10.0	9.65	9.34	9.07	8.84	8.65
1500000		91	1.412	38.2	19.8	15.9	13.9	12.7	11.9	11.0	10.4	9.94	9.56	9.25	8.99	8.77	8.57
1400000		91	1.364	36.2	19.4	15.6	13.7	12.6	11.8	10.9	10.3	9.84	9.47	9.17	8.91	8.69	8.50
1300000		91	1.315	34.4	19.0	15.3	13.5	12.4	11.6	10.8	10.2	9.73	9.37	9.07	8.82	8.61	8.42
1200000		91	1.263	32.6	18.5	15.0	13.3	12.2	11.5	10.6	10.1	9.62	9.27	8.98	8.73	8.52	8.34
1100000		91	1.209	31.0	18.1	14.8	13.1	12.0	11.3	10.5	9.94	9.50	9.16	8.87	8.63	8.43	8.25
1000000		61	1.152	29.3	17.6	14.4	12.8	11.8	11.1	10.3	9.80	9.38	9.04	8.76	8.53	8.33	8.15
950000		61	1.123	28.6	17.3	14.3	12.7	11.7	11.0	10.3	9.72	9.31	8.98	8.70	8.47	8.27	8.10
900000		61	1.093	27.8	17.1	14.1	12.6	11.6	10.9	10.2	9.65	9.24	8.91	8.64	8.42	8.22	8.05
850000		61	1.062	27.0	16.8	13.9	12.4	11.5	10.8	10.1	9.57	9.17	8.85	8.58	8.36	8.16	7.99
800000		61	1.031	26.3	16.6	13.8	12.3	11.4	10.7	10.0	9.49	9.09	8.78	8.52	8.29	8.10	7.94
750000		61	.998	25.5	16.3	13.6	12.2	11.3	10.6	9.91	9.40	9.01	8.70	8.45	8.23	8.04	7.88
700000		61	.964	24.8	16.0	13.4	12.0	11.1	10.5	9.81	9.31	8.93	8.63	8.37	8.16	7.98	7.81
650000		61	.929	24.1	15.8	13.2	11.9	11.0	10.4	9.72	9.22	8.84	8.55	8.30	8.09	7.91	7.75
600000		37	.891	23.3	15.4	13.0	11.7	10.8	10.2	9.59	9.11	8.75	8.46	8.21	8.01	7.83	7.68
550000		37	.853	22.5	15.1	12.8	11.5	10.7	10.1	9.47	9.01	8.65	8.37	8.13	7.93	7.75	7.60
500000		37	.814	21.8	14.8	12.5	11.3	10.5	9.96	9.36	8.90	8.55	8.27	8.03	7.84	7.67	7.52
450000		37	.772	21.0	14.5	12.3	11.1	10.4	9.81	9.23	8.77	8.43	8.16	7.93	7.74	7.58	7.43
400000		19	.725	20.2	14.1	12.0	10.9	10.2	9.64	9.06	8.63	8.31	8.04	7.82	7.63	7.47	7.33
350000		19	.679	19.3	13.7	11.7	10.7	9.97	9.45	8.90	8.49	8.17	7.91	7.70	7.52	7.36	7.23
300000		19	.628	18.5	13.3	11.4	10.4	9.74	9.25	8.72	8.33	8.02	7.77	7.57	7.39	7.24	7.11
250000		19	.574	17.5	12.8	11.1	10.1	9.49	9.03	8.52	8.14	7.85	7.61	7.42	7.25	7.10	6.97
211600	0000	7	.522	16.7	12.4	10.8	9.85	9.24	8.80	8.32	7.96	7.68	7.45	7.26	7.10	6.96	6.84
167806	000	7	.464	15.8	11.9	10.4	9.53	8.96	8.54	8.09	7.75	7.48	7.27	7.09	6.93	6.80	6.68
133077	00	7	.414	14.9	11.4	10.0	9.22	8.69	8.30	7.87	7.55	7.29	7.09	6.92	6.77	6.64	6.53
105535	0	7	.368	14.2	11.0	9.68	8.94	8.44	8.07	7.66	7.36	7.12	6.92	6.76	6.62	6.50	6.39
83693	1	7	.328	13.5	10.6	9.37	8.67	8.20	7.85	7.46	7.17	6.95	6.76	6.60	6.47	6.35	6.25
66371	2	7	.292	12.9	10.2	9.07	8.42	7.98	7.65	7.28	7.00	6.78	6.61	6.46	6.33	6.22	6.12
52635	3	7	.260	12.4	9.84	8.80	8.18	7.76	7.45	7.10	6.84	6.63	6.46	6.32	6.19	6.09	5.99
41741	4	7	.232	11.8	9.52	8.54	7.96	7.56	7.26	6.93	6.68	6.48	6.32	6.18	6.07	5.96	5.87
33102	5	7	.206	11.4	9.22	8.30	7.75	7.37	7.09	6.77	6.53	6.34	6.18	6.05	5.94	5.84	5.76
26251	6	7	.184	10.9	8.93	8.07	7.55	7.19	6.92	6.61	6.39	6.20	6.06	5.93	5.82	5.73	5.64

CIRCULAR MILS	B&S	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																
		3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
2000000		8.55	8.27	7.84	7.52	7.27	7.07	6.90	6.63	6.42	6.25	6.10	5.98	5.88	5.79	5.71	5.53	5.40
1900000		8.50	8.22	7.80	7.48	7.23	7.03	6.86	6.59	6.38	6.22	6.08	5.96	5.85	5.76	5.68	5.51	5.38
1800000		8.44	8.17	7.75	7.44	7.19	6.99	6.83	6.56	6.35	6.19	6.05	5.93	5.83	5.74	5.66	5.49	5.35
1700000		8.38	8.11	7.70	7.39	7.15	6.95	6.79	6.52	6.32	6.15	6.02	5.90	5.80	5.71	5.63	5.46	5.33
1600000		8.32	8.05	7.64	7.34	7.10	6.91	6.74	6.48	6.28	6.12	5.98	5.87	5.77	5.68	5.60	5.44	5.30
1500000		8.25	7.99	7.59	7.29	7.05	6.86	6.70	6.44	6.24	6.08	5.95	5.83	5.73	5.65	5.57	5.41	5.28
1400000		8.18	7.92	7.53	7.23	7.00	6.81	6.66	6.40	6.20	6.05	5.91	5.80	5.70	5.61	5.54	5.38	5.25
1300000		8.11	7.86	7.47	7.18	6.95	6.76	6.61	6.36	6.16	6.01	5.87	5.76	5.67	5.58	5.50	5.35	5.22
1200000		8.03	7.78	7.40	7.12	6.89	6.71	6.56	6.31	6.12	5.96	5.83	5.72	5.63	5.54	5.47	5.31	5.19
1100000		7.95	7.71	7.33	7.05	6.83	6.65	6.50	6.26	6.07	5.92	5.79	5.68	5.59	5.50	5.43	5.28	5.15
1000000		7.86	7.62	7.26	6.98	6.77	6.59	6.44	6.20	6.02	5.87	5.74	5.64	5.54	5.46	5.39	5.24	5.11
950000		7.81	7.58	7.22	6.94	6.73	6.56	6.41	6.17	5.99	5.84	5.72	5.61	5.52	5.44	5.37	5.21	5.09
900000		7.76	7.53	7.17	6.91	6.69	6.52	6.38	6.14	5.96	5.81	5.69	5.59	5.50	5.42	5.34	5.19	5.07
850000		7.71	7.48	7.13	6.87	6.66	6.49	6.34	6.11	5.93	5.79	5.66	5.56	5.47	5.39	5.32	5.17	5.05
800000		7.66	7.43	7.09	6.82	6.62	6.45	6.31	6.08	5.90	5.76	5.64	5.53	5.44	5.36	5.29	5.15	5.03
750000		7.60	7.38	7.04	6.78	6.58	6.41	6.27	6.04	5.87	5.72	5.61	5.50	5.41	5.34	5.27	5.12	5.00
700000		7.54	7.33	6.99	6.73	6.53	6.37	6.23	6.01	5.83	5.69	5.57	5.47	5.38	5.31	5.24	5.09	4.98
650000		7.48	7.27	6.93	6.68	6.49	6.32	6.19	5.97	5.79	5.66	5.54	5.44	5.35	5.28	5.21	5.07	4.95
600000		7.41	7.20	6.88	6.63	6.43	6.27	6.14	5.92	5.75	5.62	5.50	5.40	5.32	5.24	5.18	5.04	4.92
550000		7.34	7.14	6.81	6.57	6.38	6.22	6.09	5.88	5.71	5.58	5.46	5.37	5.28	5.21	5.14	5.00	4.89
500000		7.27	7.07	6.75	6.51	6.32	6.17	6.04	5.83	5.67	5.53	5.42	5.33	5.24	5.17	5.10	4.97	4.86
450000		7.19	6.99	6.68	6.45	6.26	6.11	5.98	5.78	5.62	5.49	5.38	5.28	5.20	5.13	5.06	4.93	4.82
400000		7.09	6.90	6.60	6.37	6.19	6.04	5.92	5.72	5.56	5.43	5.32	5.23	5.15	5.08	5.02	4.88	4.78
350000		7.00	6.81	6.51	6.29	6.12	5.97	5.85	5.65	5.50	5.37	5.27	5.18	5.10	5.03	4.97	4.84	4.73
300000		6.89	6.70	6.42	6.20	6.03	5.89	5.77	5.58	5.43	5.31	5.20	5.12	5.04	4.97	4.91	4.79	4.68
250000		6.76	6.58	6.31	6.10	5.93	5.80	5.68	5.50	5.35	5.23	5.13	5.05	4.97	4.91	4.85	4.72	4.62
211600	0000	6.63	6.46	6.20	6.00	5.84	5.70	5.59	5.41	5.27	5.16	5.06	4.98	4.90	4.84	4.78	4.66	4.56
167806	000	6.49	6.32	6.07	5.88	5.72	5.59	5.49	5.31	5.18	5.07	4.97	4.89	4.82	4.76	4.70	4.59	4.49
133077	00	6.34	6.19	5.94	5.76	5.61	5.49	5.39	5.22	5.09	4.98	4.89	4.81	4.74	4.68	4.63	4.52	4.43
105535	0	6.21	6.06	5.83	5.65	5.51	5.39	5.29	5.13	5.00	4.90	4.81	4.73	4.67	4.61	4.56	4.45	4.36
83693	1	6.08	5.94	5.71	5.54	5.40	5.29	5.19	5.04	4.92	4.81	4.73	4.66	4.59	4.54	4.49	4.38	4.29
66371	2	5.95	5.82	5.60	5.44	5.30	5.19	5.10	4.95	4.83	4.74	4.65	4.58	4.52	4.47	4.42	4.32	4.23
52635	3	5.83	5.70	5.50	5.34	5.21	5.10	5.01	4.87	4.75	4.66	4.58	4.51	4.45	4.40	4.35	4.25	4.17
41741	4	5.72	5.59	5.39	5.24	5.12	5.02	4.93	4.79	4.68	4.59	4.51	4.44	4.39	4.33	4.29	4.19	4.11
33102	5	5.61	5.49	5.29	5.15	5.03	4.93	4.85	4.71	4.60	4.52	4.44	4.38	4.32	4.27	4.23	4.13	4.06
26251	6	5.50	5.39	5.20	5.06	4.94	4.85	4.77	4.64	4.53	4.45	4.37	4.31	4.26	4.21	4.17	4.07	4.00

The values for susceptance were derived from the equation $b = 2\pi f C$. The susceptance at any other frequency f is $f/60$ times the table values.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane

The charging current in amperes per mile of single conductor to neutral equals the (susceptance from the table) × (volts to neutral) × 10^{-6}

TABLE XXII—60 CYCLE CAPACITY SUSCEPTANCE TO NEUTRAL PER MILE OF SINGLE BARE CONDUCTOR

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

60 CYCLE CAPACITY SUSCEPTANCE b TO NEUTRAL IN MICROMHOS PER MILE OF EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. THE SUSCEPTANCE BETWEEN CONDUCTORS EQUALS ONE-HALF THE TABLE VALUES.

SIZE OF CONDUCTOR: CIRCULAR MILS (ALUMINUM)	SIZE OF CONDUCTOR: AMERICAN WIRE GAUGE B&S	NUMBER OF WIRES: ALUMINUM	NUMBER OF WIRES: STEEL	OUTSIDE DIAMETER IN INCHES	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★ 2 INCHES (5.1 CM)	4 INCHES (10.2 CM)	6 INCHES (15.2 CM)	8 INCHES (20.3 CM)	10 INCHES (25.4 CM)	12 INCHES (30.5 CM)	15 INCHES (38.1 CM)	18 INCHES (45.7 CM)	21 INCHES (53.3 CM)	24 INCHES (61.0 CM)	27 INCHES (68.6 CM)	30 INCHES (76.2 CM)	33 INCHES (83.8 CM)	36 INCHES (91.4 CM)
1 590 000		54	7	1.544	1 000 000	44.9	21.0	16.6	14.5	13.2	12.3	11.4	10.7	10.2	9.81	9.49	9.21	8.98	8.77
1 510 500		54	7	1.506	950 000	42.7	20.7	16.4	14.3	13.1	12.2	11.3	10.6	10.1	9.74	9.42	9.15	8.92	8.72
1 431 000		54	7	1.465	900 000	40.6	20.3	16.2	14.2	12.9	12.1	11.2	10.5	10.1	9.66	9.35	9.08	8.85	8.66
1 351 500		54	7	1.424	850 000	38.7	19.9	15.9	14.0	12.8	12.0	11.1	10.4	9.96	9.58	9.27	9.01	8.79	8.60
1 272 000		54	7	1.382	800 000	36.9	19.5	15.7	13.8	12.6	11.8	11.0	10.3	9.87	9.50	9.20	8.94	8.72	8.52
1 192 500		54	7	1.337	750 000	35.2	19.2	15.5	13.6	12.5	11.7	10.8	10.2	9.78	9.42	9.12	8.86	8.65	8.46
1 113 000		54	7	1.292	700 000	33.6	18.8	15.2	13.4	12.3	11.6	10.7	10.1	9.69	9.33	9.03	8.78	8.57	8.38
1 033 500		54	7	1.246	650 000	32.1	18.4	15.0	13.2	12.2	11.4	10.6	10.0	9.58	9.23	8.94	8.70	8.49	8.31
954 000		54	7	1.196	600 000	30.6	18.0	14.7	13.0	12.0	11.3	10.5	9.90	9.47	9.13	8.85	8.61	8.40	8.23
900 000		54	7	1.162	566 000	29.6	17.7	14.5	12.9	11.9	11.1	10.4	9.82	9.40	9.06	8.78	8.55	8.34	8.17
874 500		54	7	1.146	550 000	29.2	17.5	14.4	12.8	11.8	11.1	10.3	9.78	9.36	9.03	8.75	8.52	8.31	8.14
795 000		54	7	1.093	500 000	27.8	17.1	14.1	12.6	11.6	10.9	10.2	9.64	9.24	8.91	8.64	8.42	8.22	8.05
715 500		54	7	1.036	450 000	26.4	16.6	13.8	12.3	11.4	10.7	10.0	9.50	9.11	8.79	8.52	8.31	8.11	7.95
666 600		54	7	1.000	419 000	25.6	16.3	13.6	12.2	11.3	10.6	9.92	9.41	9.02	8.71	8.45	8.23	8.05	7.88
636 000		54	7	.977	400 000	25.1	16.1	13.5	12.1	11.2	10.5	9.84	9.35	8.96	8.66	8.40	8.19	8.00	7.84
605 000		54	7	.953	380 500	24.6	16.0	13.3	12.0	11.1	10.5	9.78	9.29	8.91	8.60	8.35	8.14	7.96	7.80
556 500		30	7	.953	350 000	24.6	16.0	13.3	12.0	11.1	10.5	9.78	9.29	8.91	8.60	8.35	8.14	7.96	7.80
556 500		26	7	.912	350 000	23.7	15.6	13.1	11.8	10.9	10.3	9.65	9.17	8.80	8.51	8.26	8.05	7.87	7.72
518 000		42	19	1.000	326 000	25.6	16.3	13.6	12.2	11.3	10.6	9.92	9.41	9.02	8.71	8.45	8.23	8.05	7.88
500 000		30	7	.904	314 500	23.5	15.6	13.1	11.8	10.9	10.3	9.63	9.15	8.78	8.49	8.24	8.03	7.86	7.70
477 000		30	7	.883	300 000	23.1	15.4	12.9	11.7	10.8	10.2	9.56	9.09	8.73	8.43	8.19	7.99	7.81	7.66
477 000		26	7	.845	300 000	22.4	15.1	12.7	11.5	10.7	10.1	9.44	8.98	8.63	8.34	8.11	7.91	7.73	7.58
397 500		30	7	.806	250 000	21.6	14.8	12.5	11.3	10.5	9.93	9.32	8.87	8.52	8.25	8.02	7.82	7.65	7.50
397 500		26	7	.771	250 000	21.0	14.5	12.3	11.1	10.4	9.81	9.21	8.77	8.43	8.16	7.93	7.74	7.57	7.43
336 400		30	7	.741	0 000	20.4	14.2	12.1	11.0	10.2	9.70	9.11	8.68	8.35	8.08	7.86	7.67	7.51	7.37
336 400		26	7	.710	0 000	19.9	14.0	11.9	10.8	10.1	9.58	9.00	8.58	8.26	8.00	7.78	7.60	7.43	7.30
300 000		30	7	.700	188 800	19.7	13.9	11.9	10.8	10.1	9.54	8.97	8.55	8.23	7.97	7.76	7.57	7.42	7.28
300 000		26	7	.670	188 800	19.2	13.6	11.7	10.6	9.93	9.42	8.87	8.46	8.14	7.89	7.68	7.50	7.34	7.21
266 800		26	7	.632	000	18.5	13.3	11.5	10.4	9.76	9.27	8.73	8.34	8.03	7.79	7.58	7.40	7.25	7.12
266 800		6	7	.633	000	18.5	13.3	11.5	10.4	9.76	9.27	8.74	8.34	8.03	7.79	7.58	7.40	7.25	7.12
211 600	0 000	6	1	.564	00	17.4	12.7	11.0	10.1	9.44	8.98	8.48	8.11	7.82	7.58	7.39	7.22	7.08	6.95
167 806	000	6	1	.501	0	16.4	12.2	10.6	9.73	9.15	8.72	8.24	7.89	7.61	7.39	7.20	7.05	6.91	6.79
133 077	00	6	1	.447	1	15.5	11.7	10.3	9.42	8.87	8.46	8.01	7.68	7.42	7.21	7.03	6.88	6.75	6.63
105 535	0	6	1	.398	2	14.7	11.2	9.90	9.13	8.61	8.22	7.80	7.48	7.24	7.03	6.87	6.72	6.59	6.48
83 693	1	6	1	.355	3	14.0	10.8	9.58	8.85	8.36	8.00	7.59	7.30	7.06	6.87	6.71	6.57	6.45	6.34
66 371	2	6	1	.316	4	13.3	10.4	9.27	8.59	8.12	7.78	7.40	7.11	6.89	6.71	6.56	6.42	6.31	6.21
52 635	3	6	1	.281	5	12.7	10.1	8.98	8.34	7.90	7.58	7.22	6.94	6.73	6.56	6.41	6.29	6.18	6.08
41 741	4	6	1	.250	6	12.2	9.73	8.71	8.11	7.70	7.39	7.04	6.78	6.58	6.41	6.27	6.15	6.05	5.95
33 102	5	6	1	.223	7	11.7	9.41	8.46	7.89	7.50	7.20	6.88	6.63	6.44	6.27	6.14	6.02	5.92	5.83
26 251	6	6	1	.198	8	11.2	9.12	8.22	7.68	7.31	7.03	6.72	6.48	6.30	6.14	6.01	5.90	5.81	5.72

CIRCULAR MILS (ALUMINUM)	A. W. G. B&S	ALUMINUM	STEEL	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★ 3.5 FEET (1.07 M)	4 FEET (1.22 M)	5 FEET (1.52 M)	6 FEET (1.83 M)	7 FEET (2.13 M)	8 FEET (2.44 M)	9 FEET (2.74 M)	11 FEET (3.35 M)	13 FEET (3.96 M)	15 FEET (4.57 M)	17 FEET (5.18 M)	19 FEET (5.79 M)	21 FEET (6.40 M)	23 FEET (7.01 M)	25 FEET (7.62 M)	30 FEET (9.14 M)	35 FEET (10.67 M)
1 590 000		54	7	8.43	8.16	7.74	7.43	7.19	6.99	6.82	6.56	6.35	6.18	6.04	5.93	5.83	5.73	5.66	5.49	5.35
1 510 500		54	7	8.38	8.11	7.70	7.39	7.15	6.95	6.79	6.52	6.32	6.15	6.02	5.90	5.80	5.71	5.63	5.46	5.33
1 431 000		54	7	8.32	8.06	7.65	7.35	7.11	6.91	6.75	6.49	6.29	6.12	5.99	5.87	5.77	5.68	5.60	5.44	5.31
1 351 500		54	7	8.27	8.00	7.60	7.30	7.07	6.87	6.71	6.45	6.25	6.09	5.96	5.84	5.74	5.66	5.58	5.41	5.28
1 272 000		54	7	8.21	7.95	7.55	7.25	7.02	6.83	6.67	6.42	6.22	6.06	5.93	5.81	5.72	5.63	5.55	5.39	5.26
1 192 500		54	7	8.14	7.89	7.50	7.20	6.98	6.79	6.63	6.38	6.18	6.02	5.89	5.78	5.68	5.60	5.52	5.36	5.23
1 113 000		54	7	8.08	7.82	7.44	7.15	6.93	6.74	6.59	6.34	6.15	5.99	5.86	5.75	5.65	5.57	5.49	5.33	5.20
1 033 500		54	7	8.00	7.76	7.38	7.10	6.87	6.69	6.54	6.29	6.10	5.95	5.82	5.71	5.61	5.53	5.46	5.30	5.18
954 000		54	7	7.93	7.69	7.31	7.04	6.82	6.64	6.49	6.25	6.06	5.91	5.78	5.67	5.58	5.50	5.42	5.27	5.14
900 000		54	7	7.88	7.63	7.27	6.99	6.78	6.60	6.45	6.21	6.03	5.88	5.75	5.64	5.55	5.47	5.40	5.24	5.12
874 500		54	7	7.85	7.61	7.25	6.98	6.76	6.58	6.43	6.19	6.01	5.86	5.74	5.63	5.54	5.46	5.38	5.23	5.11
795 000		54	7	7.76	7.53	7.17	6.90	6.69	6.52	6.38	6.14	5.96	5.81	5.69	5.59	5.49	5.41	5.34	5.20	5.07
715 500		54	7	7.67	7.44	7.09	6.83	6.62	6.45	6.31	6.09	5.90	5.76	5.64	5.54	5.45	5.37	5.30	5.15	5.03
666 600		54	7	7.61	7.39	7.04	6.78	6.58	6.41	6.27	6.04	5.87	5.73	5.61	5.50	5.42	5.34	5.27	5.12	5.01
636 000		54	7	7.57	7.35	7.01	6.75	6.55	6.38	6.24	6.02	5.84	5.70	5.59	5.49	5.40	5.32	5.25	5.11	4.99
605 000		54	7	7.53	7.31	6.97	6.72	6.52	6.35	6.22	5.99	5.82	5.68	5.56	5.46	5.38	5.30	5.23	5.09	4.97
556 500		30	7	7.53	7.31	6.97	6.72	6.52	6.35	6.22	5.99	5.82	5.68	5.56	5.46	5.38	5.30	5.23	5.09	4.97
556 500		26	7	7.45	7.24	6.91	6.66	6.46	6.30	6.16	5.95	5.78	5.64	5.52	5.43	5.34	5.26	5.20	5.05	4.94
518 000		42	19	7.61	7.39	7.04	6.78	6.58	6.41	6.27	6.04	5.87	5.73	5.61	5.50	5.42	5.34	5.27	5.12	5.01
500 000		30	7	7.44	7.22	6.90	6.65	6.45	6.29	6.16	5.94	5.77	5.63	5.52	5.42	5.33	5.26	5.19	5.04	4.93
477 000		30	7	7.40	7.19	6.86	6.62	6.42	6.26	6.13	5.91	5.75	5.61	5.49	5.40	5.31	5.24	5.17	5.03	4.92
477 000		26	7	7.33	7.12	6.80	6.56	6.37	6.21	6.08	5.87	5.70	5.57	5.46	5.36	5.27	5.20	5.14	5.00	4.88
397 500		30	7	7.25	7.05	6.74	6.50	6.31	6.16	6.03	5.82	5.66	5.52	5.41	5.32	5.24	5.16	5.10	4.96	4.85
397 500		26	7	7.19	6.99	6.68	6.45	6.26	6.11	5.98	5.78	5.61	5.49	5.38	5.28	5.20	5.13	5.06	4.93	4.82
336 400		30	7	7.13	6.93	6.63	6.40	6.22	6.07	5.94	5.74	5.58	5.45	5.34	5.25	5.17	5.10	5.03	4.90	4.79
336 400		26	7	7.06	6.87	6.57	6.35	6.16	6.02	5.89	5.69	5.54	5.41	5.30	5.21	5.14	5.06	5.00	4.87	4.77
300 000		30	7	7.04	6.85	6.55	6.33	6.15	6.01	5.88	5.68	5.53	5.40	5.29	5.20	5.12	5.05	4.99	4.86	4.75
300 000		26	7	6.98	6.79	6.50	6.28	6.10	5.96	5.84	5.64	5.49	5.36	5.26	5.17	5.09	5.02	4.96	4.83	4.72
266 800		26	7	6.89	6.71	6.42	6.21	6.04	5.90	5.78	5.58	5.44	5.31	5.21	5.12	5.04	4.98	4.92	4.79	4.68
266 800		6	7	6.90	6.71	6.43	6.21	6.04	5.90	5.78	5.59	5.44	5.31	5.21	5.12	5.04	4.98	4.92	4.79	4.69
211 600	0 000	6	1	6.74	6.56	6.29	6.08	5.92	5.78	5.67	5.48	5.34	5.22	5.12	5.03	4.96	4.89	4.84	4.71	4.61
167 806	000	6	1	6.58	6.42	6.15	5.96	5.80	5.67	5.56	5.38	5.24	5.13	5.03	4.95	4.88	4.81	4.75	4.64	4.54
133 077	00	6	1	6.44	6.28	6.03	5.84	5.69	5.56	5.46	5.28	5.15	5.04	4.95	4.87	4.80	4.74	4.68	4.57	4.47
105 535	0	6	1	6.30	6.15	5.90	5.72	5.58	5.46	5.35	5.19	5.06	4.95	4.86	4.78	4.72	4.66	4.61	4.49	4.40
83 693	1	6	1	6.16	6.02	5.79	5.61	5.47	5.35	5.26	5.10	4.97	4.87	4.78	4.71	4.65	4.59	4.54	4.43	4.34
66 371	2	6	1	6.04	5.90	5.67	5.50	5.37	5.26	5.16	5.01	4.89	4.79	4.71	4.63	4.57	4.51	4.46	4.36	4.28
52 635	3	6	1	5.92	5.78	5.57	5.40	5.27	5.17	5.07	4.92	4.81	4.71	4.63	4.56	4.50	4.45	4.40	4.29	4.21
41 741	4	6	1	5.79	5.67	5.46	5.30	5.18	5.07	4.99	4.84	4.73	4.64	4.56	4.49	4.43	4.38	4.33	4.23	4.15
33 102	5	6	1	5.68	5.56	5.36	5.21	5.09	4.99	4.90	4.76	4.65	4.56	4.49	4.42	4.37	4.31	4.27	4.17	4.09
26 251	6	6	1	5.57	5.45	5.26	5.12	5.00	4.91	4.82	4.69	4.58	4.49	4.42	4.35	4.30	4.25	4.21	4.11	4.04

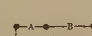
The values for susceptance were derived from the equation $b = 2\pi f C$. The susceptance at any other frequency f is $f/60$ times the table values.

The charging current in amperes per mile of single conductor to neutral equals the (susceptance from the table) × (volts to neutral) × 10^{-6}

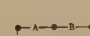
★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing

Symmetrical triangular spacing



Irregular flat spacing



Regular flat spacing

TABLE XXIII—CHARGING Kv-A IN THREE-PHASE CIRCUITS PER MILE OF THREE BARE CONDUCTORS

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

CHARGING Kv-A PER MILE (EXPRESSED IN Kv-A THREE-PHASE) FOR A THREE-PHASE CIRCUIT AT THE AVERAGE VOLTAGE AND SPACINGS OF CONDUCTORS STATED. (SEE FOOT-NOTES)

25 CYCLE CHARGING Kv-A PER MILE ★

SIZE OF CONDUCTOR: CIRCULAR MILS	SIZE OF CONDUCTOR: AMERICAN WIRE GAUGE (B&S)	NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	11 Kv. (3 FT.)	22 Kv (4 FT.)	33 Kv. (4 FT.)	44 Kv. (5 FT.)	55 Kv. (6 FT.)	66 Kv. (6 FT.)	77 Kv. (7 FT.)	88 Kv (8 FT.)	110 Kv. (9 FT.)	132 Kv (13 FT.)	165 Kv. (17 FT.)	220 Kv. (21 FT.)	264 Kv. (25 FT.)	330 Kv (30 FT.)
2000000		127	1.631	.449	1.67	3.75	6.33	9.48	13.7	18.0	22.8	34.8	46.6	69.2	119.	166.	251.
1900000		127	1.590	.446	1.66	3.73	6.29	9.43	13.6	17.9	22.7	34.6	46.4	68.9	118.	165.	250.
1800000		127	1.548	.443	1.65	3.71	6.25	9.37	13.5	17.8	22.6	34.4	46.1	68.6	118.	164.	249.
1700000		127	1.504	.439	1.64	3.68	6.21	9.31	13.4	17.7	22.4	34.2	45.9	68.2	117.	163.	248.
1600000		127	1.459	.436	1.62	3.65	6.17	9.25	13.3	17.5	22.3	34.0	45.6	67.9	116.	163.	247.
1500000		91	1.412	.432	1.61	3.63	6.12	9.19	13.2	17.4	22.1	33.8	45.3	67.5	116.	162.	245.
1400000		91	1.364	.429	1.60	3.60	6.07	9.12	13.1	17.3	22.0	33.6	45.0	67.1	115.	161.	244.
1300000		91	1.315	.425	1.58	3.56	6.02	9.05	13.0	17.2	21.8	33.3	44.7	66.6	114.	160.	243.
1200000		91	1.263	.420	1.57	3.53	5.97	8.97	12.9	17.0	21.7	33.1	44.4	66.2	114.	159.	241.
1100000		91	1.209	.416	1.55	3.50	5.91	8.89	12.8	16.9	21.5	32.8	44.1	65.7	113.	158.	239.
1000000		61	1.152	.411	1.54	3.46	5.85	8.80	12.7	16.7	21.3	32.5	43.7	65.1	112.	157.	238.
950000		61	1.123	.408	1.53	3.44	5.82	8.75	12.6	16.6	21.2	32.3	43.5	64.9	111.	156.	237.
900000		61	1.093	.406	1.52	3.42	5.79	8.71	12.5	16.5	21.0	32.2	43.3	64.6	111.	155.	236.
850000		61	1.062	.403	1.51	3.40	5.75	8.65	12.5	16.4	20.9	32.0	43.1	64.3	110.	155.	235.
800000		61	1.031	.400	1.50	3.37	5.72	8.60	12.4	16.3	20.8	31.8	42.8	63.9	110.	154.	234.
750000		61	.998	.397	1.49	3.35	5.68	8.55	12.3	16.2	20.7	31.6	42.6	63.6	109.	153.	232.
700000		61	.964	.394	1.48	3.32	5.64	8.49	12.2	16.1	20.5	31.4	42.3	63.2	109.	152.	231.
650000		61	.929	.391	1.47	3.30	5.59	8.42	12.1	16.0	20.4	31.2	42.1	62.8	108.	151.	230.
600000		37	.891	.387	1.45	3.27	5.55	8.36	12.0	15.9	20.2	31.0	41.8	62.4	107	150.	229.
550000		37	.853	.383	1.44	3.24	5.50	8.28	11.9	15.8	20.1	30.7	41.5	62.0	107.	149.	227.
500000		37	.814	.379	1.43	3.21	5.45	8.21	11.8	15.6	19.9	30.5	41.1	61.5	106.	148.	225.
450000		37	.772	.375	1.41	3.17	5.39	8.13	11.7	15.5	19.7	30.2	40.8	61.0	105.	147.	224.
400000		19	.725	.370	1.39	3.13	5.32	8.03	11.6	15.3	19.5	29.8	40.4	60.4	104.	146.	222.
350000		19	.679	.364	1.37	3.09	5.25	7.93	11.4	15.1	19.3	29.5	39.9	59.8	103.	144.	220.
300000		19	.628	.358	1.35	3.04	5.18	7.82	11.3	14.9	19.0	29.1	39.4	59.0	102.	143.	217.
250000		19	.574	.352	1.33	2.99	5.09	7.69	11.1	14.7	18.7	28.7	38.9	58.2	100.	141.	214.
211600	0000	7	.522	.345	1.30	2.93	5.00	7.56	10.9	14.4	18.4	28.2	38.3	57.4	98.9	139.	212.
167806	000	7	.464	.337	1.28	2.87	4.90	7.41	10.7	14.1	18.0	27.7	37.6	56.4	97.3	137.	208.
133077	00	7	.414	.329	1.25	2.81	4.80	7.26	10.5	13.9	17.7	27.2	36.9	55.5	95.7	135.	205.
105535	0	7	.368	.322	1.22	2.75	4.70	7.12	10.3	13.6	17.4	26.7	36.3	54.5	94.1	132.	202.
83693	1	7	.328	.315	1.20	2.69	4.61	6.98	10.1	13.4	17.1	26.2	35.7	53.7	92.6	130.	199.
66371	2	7	.292	.309	1.17	2.64	4.52	6.85	9.87	13.1	16.8	25.7	35.1	52.8	91.2	128.	196.
52635	3	7	.260	.302	1.15	2.59	4.43	6.73	9.69	12.9	16.5	25.3	34.5	52.0	89.8	126.	193.
41741	4	7	.232	.296	1.13	2.54	4.35	6.61	9.51	12.6	16.2	24.9	34.0	51.2	88.5	125.	190.
33102	5	7	.206	.290	1.11	2.49	4.27	6.49	9.34	12.4	15.9	24.4	33.4	50.4	87.1	123.	188.
26251	6	7	.184	.285	1.09	2.44	4.20	6.38	9.18	12.2	15.6	24.0	32.9	49.6	85.9	121.	185.

60 CYCLE CHARGING Kv-A PER MILE ★

CIRCULAR MILS	AMERICAN WIRE GAUGE (B&S)	NUMBER OF WIRES	OUTSIDE DIAMETER IN INCHES	11 Kv. (3 FT.)	22 Kv. (4 FT.)	33 Kv. (4 FT.)	44 Kv. (5 FT.)	55 Kv. (6 FT.)	66 Kv. (6 FT.)	77 Kv. (7 FT.)	88 Kv. (8 FT.)	110 Kv. (9 FT.)	132 Kv. (13 FT.)	165 Kv. (17 FT.)	220 Kv. (21 FT.)	264 Kv. (25 FT.)	330 Kv. (30 FT.)
2000000		127	1.631	1.08	4.00	9.01	15.2	22.8	32.8	43.1	54.7	83.5	112.	166.	285.	398.	603.
1900000		127	1.590	1.07	3.98	8.95	15.1	22.6	32.6	42.9	54.5	83.0	111.	165.	283.	396.	600.
1800000		127	1.548	1.06	3.95	8.89	15.0	22.5	32.4	42.6	54.1	82.6	111.	165.	282.	394.	598.
1700000		127	1.504	1.05	3.93	8.83	14.9	22.4	32.2	42.4	53.8	82.1	110.	164.	281.	392.	595.
1600000		127	1.459	1.05	3.90	8.77	14.8	22.2	32.0	42.1	53.5	81.6	110.	163.	279.	390.	592.
1500000		91	1.412	1.04	3.87	8.70	14.7	22.1	31.8	41.8	53.1	81.1	109.	162.	278.	388.	589.
1400000		91	1.364	1.03	3.84	8.63	14.6	21.9	31.5	41.5	52.8	80.5	108.	161.	276.	386.	586.
1300000		91	1.315	1.02	3.80	8.55	14.5	21.7	31.3	41.2	52.4	79.9	107.	160.	274.	384.	582.
1200000		91	1.263	1.01	3.77	8.48	14.3	21.5	31.0	40.9	52.0	79.3	107.	159.	272.	381.	579.
1100000		91	1.209	.998	3.73	8.39	14.2	21.3	30.7	40.5	51.5	78.7	106.	158.	270.	379.	575.
1000000		61	1.152	.986	3.69	8.30	14.1	21.1	30.4	40.1	51.0	77.9	105.	156.	268.	376.	570.
950000		61	1.123	.980	3.67	8.25	14.0	21.0	30.3	39.9	50.8	77.6	104.	156.	267.	374.	568.
900000		61	1.093	.974	3.65	8.20	13.9	20.9	30.1	39.7	50.5	77.2	104.	155.	266.	372.	566.
850000		61	1.062	.967	3.62	8.15	13.8	20.8	29.9	39.5	50.2	76.7	103.	154.	265.	371.	563.
800000		61	1.031	.960	3.60	8.10	13.7	20.6	29.7	39.2	49.9	76.3	103.	153.	263.	369.	561.
750000		61	.998	.953	3.57	8.04	13.6	20.5	29.5	39.0	49.6	75.9	102.	153.	262.	367.	558.
700000		61	.964	.946	3.55	7.98	13.5	20.4	29.3	38.7	49.3	75.4	102.	152.	261.	365.	555.
650000		61	.929	.938	3.52	7.91	13.4	20.2	29.1	38.5	49.0	74.9	101.	151.	259.	363.	552.
600000		37	.891	.929	3.49	7.84	13.3	20.1	28.9	38.2	48.6	74.3	100.	150.	257.	361.	548.
550000		37	.853	.920	3.45	7.77	13.2	19.9	28.6	37.8	48.2	73.7	99.5	149.	256.	358.	545.
500000		37	.814	.910	3.42	7.69	13.1	19.7	28.4	37.5	47.8	73.1	98.7	148.	254.	356.	541.
450000		37	.772	.899	3.38	7.61	12.9	19.5	28.1	37.1	47.3	72.4	97.9	146.	252.	353.	537.
400000		19	.725	.887	3.34	7.51	12.8	19.3	27.8	36.7	46.8	71.6	96.9	145.	249.	350.	532.
350000		19	.679	.874	3.29	7.41	12.6	19.0	27.4	36.3	46.2	70.8	95.8	143.	247.	346.	527.
300000		19	.628	.860	3.24	7.30	12.4	18.8	27.0	35.8	45.6	69.8	94.6	142.	244.	342.	521.
250000		19	.574	.844	3.19	7.17	12.2	18.5	26.6	35.2	44.9	68.8	93.2	140.	241.	338.	514.
211600	0000	7	.522	.828	3.13	7.04	12.0	18.1	26.1	34.6	44.2	67.7	91.9	138.	237.	333.	508.
167806	000	7	.464	.809	3.06	6.89	11.8	17.8	25.6	33.9	43.3	66.4	90.2	135.	233.	328.	500.
133077	00	7	.414	.791	3.00	6.74	11.5	17.4	25.1	33.3	42.5	65.2	88.6	133.	230.	323.	492.
105535	0	7	.368	.773	2.93	6.60	11.3	17.1	24.6	32.6	41.7	64.0	87.1	131.	226.	318.	484.
83693	1	7	.328	.757	2.87	6.46	11.1	16.8	24.1	32.0	41.0	62.8	85.6	129.	222.	313.	477.
66371	2	7	.292	.741	2.82	6.33	10.8	16.4	23.7	31.5	40.2	61.7	84.2	127.	219.	308.	470.
52635	3	7	.260	.725	2.76	6.21	10.6	16.1	23.2	30.9	39.5	60.7	82.8	125.	216.	303.	463.
41741	4	7	.232	.711	2.71	6.09	10.4	15.9	22.8	30.3	38.8	59.6	81.5	123.	212.	299.	456.
33102	5	7	.206	.697	2.66	5.98	10.3	15.6	22.4	29.8	38.2	58.7	80.2	121.	209.	295.	450.
26251	6	7	.184	.683	2.61	5.87	10.1	15.3	22.0	29.3	37.6	57.7	79.0	119.	206.	290.	444.

★ The charging Kv-A three-phase = (charging current in amperes to neutral) × (Kilovolts to neutral) × 3. For other spacings than those shown the charging Kv-A will vary directly as the susceptance b in Tables XIX and XXI. For other voltages than those shown the charging Kv-A will vary as the square of the voltage.

The charging current in amperes per conductor of a three-phase circuit at ZERO LOAD is equal to (auxiliary constant $\dot{C}$ for the line) × (receiving-end voltage to neutral). Therefore the charging Kv-A of a three-phase circuit at ZERO LOAD equals (charging current as found above) × (sending-end voltage to neutral.) × 3.

★ The values for conductor spacings as given under the Kv values are the values of D.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XXIV—CHARGING Kv-A IN THREE-PHASE CIRCUITS PER MILE OF THREE BARE CONDUCTORS

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

CHARGING Kv-A PER MILE (EXPRESSED IN Kv-A THREE-PHASE) FOR A THREE-PHASE CIRCUIT AT THE AVERAGE VOLTAGE AND SPACINGS OF CONDUCTORS STATED. (SEE FOOT-NOTES.)

25 CYCLE CHARGING Kv-A PER MILE ★

SIZE OF CONDUCTOR: Circular Mils (Aluminum)	SIZE OF CONDUCTOR: American Wire Gauge (B&S)	NUMBER OF WIRES: Aluminum	NUMBER OF WIRES: Steel	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin. 61%	11 Kv. (3 FT.)	22 Kv. (4 FT.)	33 Kv. (4 FT.)	44 Kv. (5 FT.)	55 Kv. (6 FT.)	66 Kv. (6 FT.)	77 Kv. (7 FT.)	88 Kv (8 FT.)	110 Kv. (9 FT.)	132 Kv. (13 FT.)	165 Kv. (17 FT.)	220 Kv. (21 FT.)	264 Kv. (25 FT.)	330 Kv. (30 FT.)
1 590 000		54	7	1 000 000	.442	1.65	3.70	6.27	9.37	13.5	17.8	22.6	34.4	46.1	68.6	118.	164	249
1 510 500		54	7	950 000	.440	1.64	3.68	6.21	9.31	13.4	17.7	22.4	34.2	45.9	68.3	117.	164	248
1 431 000		54	7	900 000	.436	1.63	3.66	6.17	9.26	13.3	17.6	22.3	34.1	45.7	67.9	116.	163	247
1 351 500		54	7	850 000	.433	1.61	3.63	6.13	9.21	13.3	17.5	22.2	33.8	45.4	67.6	116.	162	246
1 272 000		54	7	800 000	.430	1.60	3.61	6.09	9.15	13.2	17.3	22.1	33.7	45.2	67.3	115.	161	245
1 192 500		54	7	750 000	.426	1.59	3.58	6.05	9.08	13.1	17.2	21.9	33.4	44.9	66.8	115.	160	243
1 113 000		54	7	700 000	.423	1.58	3.55	6.00	9.02	13.0	17.1	21.8	33.2	44.6	66.5	114.	159	242
1 033 500		54	7	650 000	.419	1.57	3.52	5.95	8.95	12.9	17.0	21.6	33.0	44.3	66.1	113.	158	241
954 000		54	7	600 000	.415	1.55	3.49	5.90	8.87	12.8	16.8	21.4	32.7	44.0	65.6	113.	157	239
900 000		54	7	566 000	.412	1.54	3.46	5.86	8.82	12.7	16.8	21.3	32.5	43.8	65.2	112.	157	238
874 500		54	7	550 000	.410	1.54	3.45	5.85	8.79	12.7	16.7	21.2	32.4	43.7	65.1	112.	156	237
795 000		54	7	500 000	406	1.52	3.42	5.79	8.70	12.5	16.5	21.1	32.2	43.3	64.6	111.	155	236
715 500		54	7	450 000	.401	1.50	3.38	5.72	8.61	12.4	16.4	20.8	31.8	42.9	64.0	110.	154	234
666 600		54	7	419 000	.397	1.49	3.35	5.68	8.55	12.3	16.3	20.7	31.6	42.6	63.6	109.	153	233
636 000		54	7	400 000	.395	1.48	3.34	5.65	8.51	12.3	16.2	20.6	31.5	42.4	63.4	109.	153	232
605 000		54	7	380 500	.393	1.47	3.32	5.62	8.47	12.2	16.1	20.5	31.4	42.3	63.1	108.	152	231
556 500		30	7	350 000	.393	1.47	3.32	5.62	8.47	12.2	16.1	20.5	31.4	42.3	63.1	108.	152	231
556 500		26	7	350 000	.389	1.46	3.28	5.57	8.39	12.1	16.0	20.3	31.1	41.9	62.7	108.	151	229
518 000		42	19	326 000	.397	1.49	3.35	5.68	8.55	12.3	16.3	20.7	31.6	42.6	63.6	109.	153	233
500 000		30	7	314 500	.388	1.46	3.28	5.56	8.38	12.1	15.9	20.3	31.0	41.9	62.6	108.	151	229
477 000		30	7	300 000	386	1.45	3.26	5.54	8.34	12.0	15.9	20.2	30.9	41.7	62.3	107.	150	228
477 000		26	7	300 000	.382	1.44	3.23	5.49	8.27	11.9	15.7	20.1	30.7	41.4	61.9	106.	149	227
397 500		30	7	250 000	.378	1.42	3.20	5.43	8.19	11.8	15.6	19.9	30.4	41.1	61.4	106.	148	225
397 500		26	7	250 000	375	1.41	3.17	5.39	8.13	11.7	15.5	19.7	30.2	40.8	61.0	105.	147	224
336 400		30	7	0000	.372	1.40	3.14	5.35	8.07	11.6	15.4	19.6	30.0	40.5	60.6	104.	146	222
336 400		26	7	0000	.368	1.39	3.12	5.30	8.00	11.5	15.2	19.4	29.7	40.2	60.2	104.	145	221
300 000		30	7	188 800	367	1.38	3.11	5.29	7.98	11.5	15.2	19.4	29.7	40.1	60.1	103.	145	221
300 000		26	7	188 800	.364	1.37	3.08	5.24	7.91	11.4	15.1	19.2	29.4	39.8	59.6	103.	144	219
266 800		26	7	000	.359	1.35	3.05	5.19	7.83	11.3	14.9	19.0	29.1	39.5	59.1	102.	143	217
266 800		6	7	000	.359	1.35	3.05	5.19	7.83	11.3	14.9	19.0	29.1	39.5	59.1	102.	143	217
211 600	0000	6	1	00	.350	1.32	2.98	5.07	7.67	11.0	14.6	18.7	28.6	38.7	58.1	100.	141	214
167 806	000	6	1	0	.342	1.29	2.91	4.96	7.51	10.8	14.3	18.3	28.0	38.1	57.1	98.3	138	210
133 077	00	6	1	1	.334	1 27	2.85	4.86	7.36	10.6	14.1	17.9	27.5	37.4	56.1	96.7	136	207
105 535	0	6	1	2	.327	1.24	2.79	4.76	7.22	10.4	13.8	17.6	27.0	36.7	55.2	95.2	134	204
83 693	1	6	1	3	.320	1 21	2.73	4.67	7.07	10.2	13.5	17.3	26.5	36.1	54.2	93.7	132	201
66 371	2	6	1	4	.313	1 19	2.68	4.58	6.94	9.99	13.3	17.0	26.0	35.5	53.4	92.2	130	198
52 635	3	6	1	5	.306	1.17	2.62	4.49	6.81	9.81	13.0	16.7	25.6	34.9	52.5	90.7	128	195
41 741	4	6	1	6	.300	1.14	2.57	4.40	6.69	9.63	12.8	16.4	25.1	34.3	51.7	89.4	126	192
33 102	5	6	1	7	.294	1.12	2.52	4.33	6.57	9.46	12.6	16.1	24.7	33.8	50.9	88.0	124	189
26 251	6	6	1	8	.288	1.10	2.47	4.25	6.45	9.29	12.4	15.8	24.3	33.3	50.1	86.7	122	187

60 CYCLE CHARGING Kv-A PER MILE ★

Circular Mils (Aluminum)	American Wire Gauge (B&S)	Aluminum	Steel	Copper Equivalent	11 Kv. (3 FT.)	22 Kv. (4 FT.)	33 Kv. (4 FT.)	44 Kv. (5 FT.)	55 Kv. (6 FT.)	66 Kv. (6 FT.)	77 Kv. (7 FT.)	88 Kv (8 FT.)	110 Kv. (9 FT.)	132 Kv. (13 FT.)	165 Kv. (17 FT.)	220 Kv. (21 FT.)	264 Kv. (25 FT.)	330 Kv. (30 FT.)
1 590 000		54	7	1 000 000	1.06	3.95	8.89	15.0	22.5	32.4	42.6	54.1	82.6	111.	165	282	394	597
1 510 500		54	7	950 000	1.06	3.93	8.84	14.9	22.4	32.2	42.4	53.8	82.1	110.	164	281	392	595
1 431 000		54	7	900 000	1.05	3.90	8.78	14.8	22.2	32.0	42.1	53.5	81.7	110.	163	279	390	592
1 351 500		54	7	850 000	1.04	3.87	8.72	14.7	22.1	31.8	41.9	53.2	81.2	109.	162	278	389	590
1 272 000		54	7	800 000	1.03	3.85	8.65	14.6	21.9	31.6	41.6	52.9	80.7	108.	161	277	387	587
1 192 500		54	7	750 000	1.02	3.82	8.59	14.5	21.8	31.4	41.4	52.6	80.2	108.	160	275	385	584
1 113 000		54	7	700 000	1.01	3.79	8.52	14.4	21.6	31.2	41.1	52.2	79.7	107.	160	274	383	581
1 033 500		54	7	650 000	1.01	3.76	8.45	14.3	21.5	30.9	40.8	51.8	79.1	106.	159	272	380	577
954 000		54	7	600 000	.995	3.72	8.37	14.2	21.3	30.6	40.4	51.4	78.5	106.	157	270	378	574
900 000		54	7	566 000	.989	3.70	8.31	14.1	21.2	30.5	40.2	51.1	78.1	105.	157	269	376	571
874 500		54	7	550 000	.985	3.68	8.29	14.0	21.1	30.4	40.1	51.0	77.8	105.	156	268	375	570
795 000		54	7	500 000	.974	3.64	8.20	13.9	20.9	30.1	39.7	50.5	77.1	104.	155	266	372	566
715 500		54	7	450 000	.962	3.60	8.10	13.7	20.7	29.8	39.3	50.0	76.4	103.	154	264	369	561
666 600		54	7	419 000	.954	3.57	8.04	13.6	20.5	29.5	39.0	49.7	75.9	102.	153	262	367	558
636 000		54	7	400 000	.948	3.56	8.00	13.6	20.4	29.4	38.8	49.4	75.5	102.	152	261	366	556
605 000		54	7	380 500	.943	3.54	7.96	13.5	20.3	29.3	38.7	49.2	75.2	101.	151	260	364	554
556 500		30	7	350 000	.943	3.54	7.96	13.5	20.3	29.3	38.7	49.2	75.2	101.	151	260	364	554
556 500		26	7	350 000	.934	3.50	7.88	13.4	20.1	29.0	38.3	48.8	74.6	101.	150	258	362	550
518 000		42	19	326 000	.954	3.57	8.04	13.6	20.5	29.5	39.0	49.7	75.9	102.	153	262	367	558
500 000		30	7	314 500	.932	3.50	7.87	13.4	20.1	29.0	38.2	48.7	74.5	101.	150	258	362	549
477 000		30	7	300 000	.927	3.48	7.83	13.3	20.0	28.8	38.1	48.5	74.2	100.	150	257	360	548
477 000		26	7	300 000	.917	3.45	7.76	13.2	19.8	28.6	37.8	48.1	73.6	99.3	149	255	358	544
397 500		30	7	250 000	.908	3.41	7.68	13.0	19.7	28.3	37.4	47.7	72.9	98.5	147	254	355	540
397 500		26	7	250 000	.899	3.38	7.61	12.9	19.5	28.1	37.1	47.3	72.4	97.8	146	252	353	537
336 400		30	7	0000	.891	3.35	7.55	12.8	19.4	27.9	36.9	47.0	71.9	97.2	145	250	351	534
336 400		26	7	0000	.883	3.33	7.48	12.7	19.2	27.6	36.6	46.6	71.3	96.5	144	249	349	531
300 000		30	7	188 800	.880	3.32	7.46	12.7	19.2	27.6	36.5	46.5	71.2	96.3	144	248	348	529
300 000		26	7	188 800	.872	3.29	7.39	12.6	19.0	27.3	36.2	46.1	70.6	95.6	143	246	346	526
266 800		26	7	000	.861	3.25	7.31	12.4	18.8	27.1	35.8	45.7	69.9	94.7	142	244	343	521
266 800		6	7	000	.861	3.25	7.31	12.4	18.8	27.1	35.8	45.7	69.9	94.7	142	244	343	522
211 600	0 000	6	1	00	.841	3.18	7.14	12.2	18.4	26.5	35.1	44.8	68.6	93.0	139	240	337	513
167 806	000	6	1	0	.821	3.11	6.99	11.9	18.0	26.0	34.4	43.9	67.2	91.3	137	236	331	505
133 077	00	6	1	1	.802	3.04	6.84	11.7	17.7	25.4	33.7	43.1	66.0	89.7	135	232	326	497
105 535	0	6	1	2	.785	2.97	6.69	11.4	17.3	24.9	33.1	42.2	64.8	88.2	132	228	321	489
83 693	1	6	1	3	.767	2.91	6.55	11.2	17.0	24.4	32.4	41.5	63.6	86.7	130	225	316	482
66 371	2	6	1	4	.751	2.85	6.42	11.0	16.7	24.0	31.8	40.7	62.5	85.1	128	221	311	475
52 635	3	6	1	5	.735	2.80	6.29	10.8	16.3	23.5	31.3	40.0	61.4	83.8	126	218	306	468
41 741	4	6	1	6	.720	2.74	6.17	10.6	16.0	23.1	30.7	39.3	60.4	82.4	124	214	302	461
33 102	5	6	1	7	.706	2.69	6.05	10.4	15.8	22.7	30.2	38.6	59.3	81.1	122	211	298	454
26 251	6	6	1	8	.692	2.64	5.94	10.2	15.5	22.3	29.6	38.0	58.4	79.8	120	208	293	448

★ The charging Kv-A three-phase = (charging current in amperes to neutral) × (Kilovolts to neutral) × 3. For other spacings than those shown the charging Kv-A will vary directly as the susceptance b in Tables XX and XXII. For other voltages than those shown the charging Kv-A will vary as the square of the voltage. Branch circuits connected to the main line should not be overlooked.

The charging current in amperes per conductor of a three-phase circuit at ZERO LOAD is equal to (auxiliary constant C for the line) × (receiving-end voltage to neutral). Therefore the charging Kv-A of a three-phase circuit at ZERO LOAD equals (charging current as found above) × (sending-end voltage to neutral.) × 3.

★ The values for conductor spacings as given under the Kv values are the values of D. Actually the magnetizing current of connected lowering transformers will neutralize part of the charging current.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XXV—TOTAL 60 CYCLE RESISTANCE AND TOTAL 60 CYCLE REACTANCE

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

1 MILE—1.61 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.0934	.510	.537	.559	.578	.594	.621	.643	.662	.678
600 000		.101	.516	.543	.565	.584	.600	.627	.649	.668	.684
550 000		.109	.521	.548	.570	.589	.605	.632	.654	.673	.689
500 000		.120	.527	.554	.576	.595	.611	.638	.660	.679	.695
450 000		.132	.533	.560	.582	.601	.617	.644	.667	.685	.701
400 000		.148	.542	.569	.592	.610	.627	.654	.676	.694	.711
350 000		.169	.551	.578	.600	.618	.635	.662	.684	.703	.719
300 000		.197	.560	.587	.609	.628	.644	.671	.693	.712	.728
250 000		.235	.571	.598	.620	.639	.655	.682	.704	.723	.739
211 600	0000	.278	.588	.615	.637	.656	.672	.699	.721	.740	.756
167 806	000	.350	.602	.629	.651	.670	.686	.713	.735	.754	.770
133 077	00	.440	.616	.643	.665	.684	.700	.727	.749	.768	.784
105 535	0	.555	.630	.657	.679	.698	.714	.741	.763	.782	.798
83 693	1	.700	.644	.671	.693	.712	.728	.755	.777	.796	.812
66 371	2	.882	.658	.685	.707	.726	.742	.769	.791	.810	.826
52 635	3	1.11	.672	.699	.721	.740	.756	.783	.805	.824	.840
41 741	4	1.40	.686	.713	.735	.754	.770	.797	.819	.838	.854
33 102	5	1.77	.700	.727	.749	.768	.784	.811	.834	.852	.868
26 251	6	223	.714	.741	.764	.782	.798	.826	.848	.866	.883

2 MILES—3.22 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.187	1.02	1.07	1.12	1.16	1.19	1.24	1.29	1.32	1.36
600 000		.201	1.03	1.09	1.13	1.17	1.20	1.25	1.30	1.34	1.37
550 000		.219	1.04	1.10	1.14	1.18	1.21	1.26	1.31	1.35	1.38
500 000		.239	1.05	1.11	1.15	1.19	1.22	1.28	1.32	1.36	1.39
450 000		.265	1.07	1.12	1.17	1.20	1.24	1.29	1.33	1.37	1.40
400 000		.297	1.09	1.14	1.18	1.22	1.25	1.31	1.35	1.39	1.42
350 000		.338	1.10	1.16	1.20	1.24	1.27	1.32	1.37	1.41	1.44
300 000		.393	1.12	1.17	1.22	1.26	1.29	1.34	1.39	1.42	1.46
250 000		.471	1.14	1.20	1.24	1.28	1.31	1.36	1.41	1.45	1.48
211 600	0000	.555	1.18	1.23	1.27	1.31	1.34	1.40	1.44	1.48	1.51
167 806	000	.699	1.20	1.26	1.30	1.34	1.37	1.43	1.47	1.51	1.54
133 077	00	.881	1.23	1.29	1.33	1.37	1.40	1.45	1.50	1.54	1.57
105 535	0	1.11	1.26	1.31	1.36	1.40	1.43	1.48	1.53	1.56	1.60
83 693	1	1.40	1.29	1.34	1.39	1.42	1.46	1.51	1.55	1.59	1.62
66 371	2	1.76	1.32	1.37	1.41	1.45	1.48	1.54	1.58	1.62	1.65
52 635	3	2.22	1.34	1.40	1.44	1.48	1.51	1.57	1.61	1.65	1.68
41 741	4	2.80	1.37	1.43	1.47	1.51	1.54	1.60	1.64	1.68	1.71
33 102	5	3.54	1.40	1.46	1.50	1.54	1.57	1.62	1.67	1.70	1.74
26 251	6	4.46	1.43	1.48	1.53	1.56	1.60	1.65	1.70	1.73	1.77

3 MILES—4.83 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.280	1.53	1.61	1.68	1.73	1.78	1.86	1.93	1.99	2.04
600 000		.302	1.55	1.63	1.70	1.75	1.80	1.88	1.95	2.00	2.05
550 000		.328	1.56	1.64	1.71	1.77	1.82	1.90	1.96	2.02	2.07
500 000		.359	1.58	1.66	1.73	1.78	1.83	1.91	1.98	2.04	2.09
450 000		.397	1.60	1.68	1.75	1.80	1.85	1.93	2.00	2.06	2.10
400 000		.445	1.63	1.71	1.78	1.83	1.88	1.96	2.03	2.08	2.13
350 000		.507	1.65	1.73	1.80	1.86	1.90	1.99	2.05	2.11	2.16
300 000		.590	1.68	1.76	1.83	1.88	1.93	2.01	2.08	2.14	2.18
250 000		.706	1.71	1.79	1.86	1.92	1.97	2.05	2.11	2.17	2.22
211 600	0000	.833	1.76	1.84	1.91	1.97	2.02	2.10	2.16	2.22	2.27
167 806	000	1.05	1.81	1.89	1.95	2.01	2.06	2.14	2.21	2.26	2.31
133 077	00	1.32	1.85	1.93	2.00	2.05	2.10	2.18	2.25	2.30	2.35
105 535	0	1.67	1.89	1.97	2.04	2.09	2.14	2.22	2.29	2.35	2.39
83 693	1	2.10	1.93	2.01	2.08	2.14	2.18	2.27	2.33	2.39	2.44
66 371	2	2.65	1.97	2.06	2.12	2.18	2.23	2.31	2.37	2.43	2.48
52 635	3	3.34	2.02	2.10	2.16	2.22	2.27	2.35	2.42	2.47	2.52
41 741	4	4.21	2.06	2.14	2.21	2.26	2.31	2.39	2.46	2.51	2.56
33 102	5	5.30	2.10	2.18	2.25	2.30	2.35	2.43	2.50	2.56	2.61
26 251	6	6.69	2.14	2.22	2.29	2.35	2.40	2.48	2.54	2.60	2.65

4 MILES—6.44 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.374	2.04	2.15	2.24	2.31	2.38	2.49	2.57	2.65	2.71
600 000		.403	2.06	2.17	2.26	2.34	2.40	2.51	2.60	2.67	2.74
550 000		.437	2.08	2.19	2.28	2.36	2.42	2.53	2.62	2.69	2.76
500 000		.479	2.11	2.22	2.30	2.38	2.44	2.55	2.64	2.72	2.78
450 000		.530	2.13	2.24	2.33	2.40	2.47	2.58	2.67	2.74	2.81
400 000		.594	2.17	2.28	2.37	2.44	2.51	2.61	2.70	2.78	2.84
350 000		.676	2.20	2.31	2.40	2.47	2.54	2.65	2.74	2.81	2.88
300 000		.786	2.24	2.35	2.44	2.51	2.58	2.68	2.77	2.85	2.91
250 000		.942	2.28	2.39	2.48	2.56	2.62	2.73	2.82	2.89	2.96
211 600	0000	1.11	2.35	2.46	2.55	2.62	2.69	2.80	2.88	2.96	3.02
167 806	000	1.40	2.41	2.52	2.60	2.68	2.74	2.85	2.94	3.02	3.08
133 077	00	1.76	2.46	2.57	2.66	2.74	2.80	2.91	3.00	3.07	3.14
105 535	0	2.22	2.52	2.63	2.72	2.79	2.86	2.96	3.05	3.13	3.19
83 693	1	2.80	2.58	2.68	2.77	2.85	2.91	3.02	3.11	3.18	3.25
66 371	2	3.53	2.63	2.74	2.83	2.90	2.97	3.08	3.17	3.24	3.31
52 635	3	4.45	2.69	2.80	2.89	2.96	3.03	3.13	3.22	3.30	3.36
41 741	4	5.61	2.74	2.85	2.94	3.02	3.08	3.19	3.28	3.35	3.42
33 102	5	7.07	2.80	2.91	3.00	3.07	3.14	3.25	3.33	3.41	3.47
26 251	6	8.92	2.86	2.97	3.05	3.13	3.19	3.30	3.39	3.47	3.53

5 MILES—8.05 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.467	2.55	2.69	2.80	2.89	2.97	3.11	3.22	3.31	3.39
600 000		.504	2.58	2.71	2.83	2.92	3.00	3.14	3.25	3.34	3.42
550 000		.547	2.61	2.74	2.85	2.95	3.03	3.16	3.27	3.37	3.45
500 000		.599	2.63	2.77	2.88	2.97	3.06	3.19	3.30	3.39	3.48
450 000		.662	2.67	2.80	2.91	3.01	3.09	3.22	3.33	3.43	3.51
400 000		.742	2.71	2.85	2.96	3.05	3.13	3.27	3.38	3.47	3.55
350 000		.845	2.75	2.89	3.00	3.09	3.17	3.31	3.42	3.51	3.59
300 000		.983	2.80	2.94	3.05	3.14	3.22	3.36	3.47	3.56	3.64
250 000		1.18	2.86	2.99	3.10	3.19	3.28	3.41	3.52	3.62	3.70
211 600	0000	1.39	2.94	3.07	3.18	3.28	3.36	3.49	3.61	3.70	3.78
167 806	000	1.75	3.01	3.14	3.26	3.35	3.43	3.57	3.68	3.77	3.85
133 077	00	2.20	3.08	3.22	3.33	3.42	3.50	3.64	3.75	3.84	3.92
105 535	0	2.78	3.15	3.29	3.40	3.49	3.57	3.71	3.82	3.91	3.99
83 693	1	3.50	3.22	3.36	3.47	3.56	3.64	3.78	3.89	3.98	4.06
66 371	2	4.41	3.29	3.43	3.54	3.63	3.71	3.85	3.96	4.05	4.13
52 635	3	5.56	3.36	3.50	3.61	3.70	3.78	3.92	4.03	4.12	4.20
41 741	4	7.01	3.43	3.57	3.68	3.77	3.85	3.99	4.10	4.19	4.27
33 102	5	8.84	3.50	3.64	3.75	3.84	3.92	4.06	4.17	4.26	4.34
26 251	6	11.2	3.57	3.71	3.82	3.91	3.99	4.13	4.24	4.33	4.41

6 MILES—9.66 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.561	3.06	3.22	3.36	3.47	3.57	3.73	3.86	3.97	4.07
600 000		.604	3.10	3.26	3.39	3.50	3.60	3.76	3.90	4.01	4.10
550 000		.656	3.13	3.29	3.42	3.53	3.63	3.79	3.93	4.04	4.14
500 000		.718	3.16	3.32	3.46	3.57	3.67	3.83	3.96	4.07	4.17
450 000		.794	3.20	3.36	3.49	3.61	3.70	3.87	4.00	4.11	4.21
400 000		.890	3.25	3.42	3.55	3.66	3.76	3.92	4.05	4.17	4.26
350 000		1.01	3.30	3.47	3.60	3.71	3.81	3.97	4.10	4.22	4.31
300 000		1.18	3.36	3.52	3.65	3.77	3.86	4.03	4.16	4.27	4.37
250 000		1.41	3.43	3.59	3.72	3.83	3.93	4.09	4.23	4.34	4.44
211 600	0000	1.67	3.53	3.69	3.82	3.93	4.03	4.19	4.33	4.44	4.54
167 806	000	2.10	3.61	3.77	3.91	4.02	4.12	4.28	4.41	4.52	4.62
133 077	00	2.64	3.70	3.86	3.99	4.10	4.20	4.36	4.50	4.61	4.70
105 535	0	3.33	3.78	3.94	4.07	4.19	4.28	4.45	4.58	4.69	4.79
83 693	1	4.20	3.86	4.03	4.16	4.27	4.37	4.53	4.66	4.78	4.87
66 371	2	5.29	3.95	4.11	4.24	4.36	4.45	4.62	4.75	4.86	4.96
52 635	3	6.67	4.03	4.20	4.33	4.44	4.54	4.70	4.83	4.95	5.04
41 741	4	8.41	4.12	4.28	4.41	4.52	4.62	4.78	4.92	5.03	5.13
33 102	5	10.6	4.20	4.36	4.50	4.61	4.71	4.87	5.00	5.11	5.21
26 251	6	13.4	4.29	4.45	4.58	4.69	4.79	4.95	5.09	5.20	5.30

7 MILES—11.27 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.654	3.57	3.76	3.92	4.05	4.16	4.35	4.50	4.64	4.75
600 000		.705	3.61	3.80	3.96	4.09	4.20	4.39	4.54	4.68	4.79
550 000		.765	3.65	3.84	3.99	4.12	4.24	4.43	4.58	4.71	4.83
500 000		.838	3.69	3.88	4.03	4.16	4.28	4.47	4.62	4.75	4.87
450 000		.927	3.73	3.92	4.08	4.21	4.32	4.51	4.67	4.80	4.91
400 000		1.04	3.80	3.99	4.14	4.27	4.39	4.58	4.73	4.86	4.97
350 000		1.18	3.85	4.04	4.20	4.33	4.44	4.63	4.79	4.92	5.03
300 000		1.38	3.92	4.11	4.26	4.39	4.51	4.70	4.85	4.98	5.10
250 000		1.65	4.00	4.19	4.34	4.47	4.59	4.77	4.93	5.06	5.17
211 600	0000	1.94	4.11	4.30	4.46	4.59	4.70	4.89	5.05	5.18	5.29
167 806	000	2.45	4.21	4.40	4.56	4.69	4.80	4.99	5.15	5.28	5.39
133 077	00	3.08	4.31	4.50	4.66	4.79	4.90	5.09	5.24	5.38	5.49
105 535	0	3.88	4.41	4.60	4.75	4.89	5.00	5.19	5.34	5.47	5.59
83 693	1	4.90	4.51	4.70	4.85	4.98	5.10	5.29	5.44	5.57	5.69
66 371	2	6.17	4.61	4.80	4.95	5.08	5.20	5.38	5.54	5.67	5.78
52 635	3	7.78	4.71	4.89	5.05	5.18	5.29	5.48	5.64	5.77	5.88
41 741	4	9.81	4.80	4.99	5.15	5.28	5.39	5.58	5.74	5.87	5.98
33 102	5	12.4	4.90	5.09	5.25	5.38	5.49	5.68	5.84	5.97	6.08
26 251	6	15.6	5.00	5.19	5.35	5.48	5.59	5.78	5.93	6.06	6.18

8 MILES—12.87 Km.

Circular Mils	American Wire Gauge (B&S)	Total Resistance R ★	X 2 Feet (0.61 M)	X 2.5 Feet (0.76 M)	X 3 Feet (0.91 M)	X 3.5 Feet (1.07 M)	X 4 Feet (1.22 M)	X 5 Feet (1.52 M)	X 6 Feet (1.83 M)	X 7 Feet (2.13 M)	X 8 Feet (2.44 M)
650 000		.747	4.08	4.30	4.47	4.62	4.75	4.97	5.15	5.30	5.43
600 000		.806	4.13	4.34	4.52	4.67	4.80	5.02	5.19	5.34	5.47
550 000		.874	4.17	4.39	4.56	4.71	4.84	5.06	5.23	5.38	5.51
500 000		.958	4.21	4.43	4.61	4.76	4.89	5.10	5.28	5.43	5.56
450 000		1.06	4.27	4.48	4.66	4.81	4.94	5.16	5.33	5.48	5.61
400 000		1.19	4.34	4.56	4.73	4.88	5.01	5.23	5.41	5.56	5.69
350 000		1.35	4.40	4.62	4.80	4.95	5.08	5.29	5.47	5.62	5.75
300 000		1.57	4.48	4.70	4.87	5.02	5.15	5.37	5.55	5.69	5.82
250 000		1.88	4.57	4.78	4.96	5.11	5.24	5.46	5.63	5.78	5.91
211 600	0000	2.22	4.70	4.92	5.09	5.25	5.37	5.59	5.77	5.92	6.05
167 806	000	2.80	4.81	5.03	5.21	5.36	5.49	5.70	5.88	6.03	6.16
133 077	00	3.52	4.93	5.14	5.32	5.47	5.60	5.82	5.99	6.14	6.27
105 535	0	4.44	5.04	5.26	5.43	5.58	5.71	5.93	6.11	6.26	6.39
83 693	1	5.60	5.15	5.37	5.55	5.69	5.82	6.04	6.22	6.37	6.50
66 371	2	7.06	5.26	5.48	5.66	5.81	5.94	6.15	6.33	6.48	6.61
52 635	3	8.90	5.38	5.59	5.77	5.92	6.05	6.27	6.44	6.59	6.72
41 741	4	11.2	5.49	5.71	5.88	6.03	6.16	6.38	6.56	6.71	6.83
33 102	5	14.1	5.60	5.82	6.00	6.15	6.27	6.49	6.67	6.82	6.95
26 251	6	17.8	5.71	5.93	6.11	6.26	6.39	6.60	6.78	6.93	7.06

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

★ These 60 cycle resistances are for hard drawn copper at 25° C. (77° F.)

TABLE XXVI—TOTAL 60 CYCLE RESISTANCE AND 60 CYCLE REACTANCE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

Size of conductor: Circular mils (aluminum)	Size of conductor: American wire gauge B&S	Number of wires: Alum	Number of wires: Steel	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	1 MILE—1.61 Km.: Total resistance R	Total reactance X for spacings D given below: 2 feet 0.61 M	2.5 feet 0.76 M	3 feet 0.91 M	3.5 feet 1.07 M	4 feet 1.22 M	5 feet 1.52 M	6 feet 1.83 M	7 feet 2.13 M	8 feet 2.44 M	2 MILES—3.22 Km.: Total resistance R	Total reactance X for spacings D given below: 2 feet 0.61 M	2.5 feet 0.76 M	3 feet 0.91 M	3.5 feet 1.07 M	4 feet 1.22 M	5 feet 1.52 M	6 feet 1.83 M	7 feet 2.13 M	8 feet 2.44 M
1 033 500		54	7	650 000	.092	.449	.476	.498	.517	.533	.560	.583	.601	.618	.185	.898	.952	.997	1.03	1.07	1.12	1.17	1.20	1.24
954 000		54	7	600 000	.100	.454	.481	.503	.522	.538	.565	.587	.606	.622	.199	.908	.962	1.01	1.04	1.08	1.13	1.18	1.21	1.25
874 500		54	7	550 000	.109	.459	.486	.508	.527	.543	.570	.592	.611	.627	.218	.918	.972	1.02	1.05	1.09	1.14	1.19	1.22	1.25
795 000		54	7	500 000	.119	.465	.492	.514	.532	.549	.576	.598	.616	.633	.239	.929	.983	1.03	1.07	1.10	1.15	1.20	1.23	1.27
715 500		54	7	450 000	.133	.471	.498	.520	.539	.555	.582	.604	.623	.639	.265	.942	.996	1.04	1.08	1.11	1.16	1.21	1.25	1.28
636 000		54	7	400 000	.149	.478	.505	.527	.546	.562	.589	.612	.630	.646	.299	.956	1.01	1.06	1.09	1.12	1.18	1.22	1.26	1.29
556 500		30	7	350 000	.168	.481	.508	.530	.549	.565	.592	.614	.633	.649	.335	.961	1.02	1.06	1.10	1.13	1.18	1.23	1.27	1.30
477 000		30	7	300 000	.196	.491	.518	.540	.558	.575	.602	.624	.642	.659	.391	.981	1.04	1.08	1.12	1.15	1.20	1.25	1.29	1.32
397 500		30	7	250 000	.235	.503	.530	.552	.570	.587	.614	.636	.655	.671	.470	1.01	1.06	1.10	1.14	1.17	1.23	1.27	1.31	1.34
336 400		30	7	0 000	.278	.513	.540	.563	.581	.597	.624	.647	.665	.681	.555	1.03	1.08	1.13	1.16	1.19	1.25	1.29	1.33	1.36
266 800		26	7	000	.350	.532	.560	.582	.600	.616	.644	.666	.684	.701	.700	1.07	1.12	1.16	1.20	1.23	1.29	1.33	1.37	1.40
211 600	0 000	6	1	00	.464	.628	.655	.677	.696	.712	.739	.761	.780	.796	.928	1.26	1.31	1.35	1.39	1.42	1.48	1.52	1.56	1.59
167 806	000	6	1	0	.579	.638	.665	.687	.706	.722	.749	.771	.790	.807	1.16	1.28	1.33	1.38	1.41	1.44	1.50	1.54	1.58	1.61
133 077	00	6	1	1	.718	.648	.676	.69[illegible]	.716	.733	.760	.782	.800	.817	1.44	1.30	1.35	1.40	1.43	1.47	1.52	1.56	1.60	1.63
105 535	0	6	1	2	.893	.659	.686	.708	.727	.743	.770	.793	.811	.827	1.79	1.32	1.37	1.42	1.45	1.49	1.54	1.59	1.62	1.65
83 693	1	6	1	3	1.12	.670	.698	.720	.738	.754	.782	.804	.822	.838	2.24	1.34	1.40	1.44	1.48	1.51	1.56	1.61	1.64	1.68
66 371	2	6	1	4	1.41	.681	.708	.730	.749	.765	.792	.814	.833	.849	2.82	1.36	1.42	1.46	1.50	1.53	1.58	1.63	1.67	1.70
52 635	3	6	1	5	1.78	.691	.719	.741	.759	.776	.803	.825	.843	.860	3.55	1.38	1.44	1.48	1.52	1.55	1.61	1.65	1.69	1.72
41 741	4	6	1	6	2.24	.702	.730	.752	.770	.786	.814	.836	.854	.871	4.47	1.41	1.46	1.50	1.54	1.57	1.63	1.67	1.71	1.74

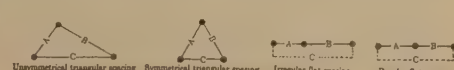
Circular mils (aluminum)	A. W. G. B&S	Alum	Steel	Copper equivalent	3 MILES—4.83 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet	4 MILES—6.44 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet
1 033 500		54	7	650 000	.277	1.35	1.43	1.50	1.55	1.60	1.68	1.75	1.80	1.85	.369	1.80	1.91	1.99	2.07	2.13	2.24	2.33	2.41	2.47
954 000		54	7	600 000	.299	1.36	1.44	1.51	1.57	1.62	1.70	1.76	1.82	1.87	.399	1.82	1.92	2.01	2.09	2.15	2.26	2.35	2.43	2.49
874 500		54	7	550 000	.327	1.38	1.46	1.52	1.58	1.63	1.71	1.78	1.83	1.88	.436	1.84	1.94	2.03	2.11	2.17	2.28	2.37	2.44	2.51
795 000		54	7	500 000	.358	1.39	1.48	1.54	1.60	1.65	1.73	1.79	1.85	1.90	.477	1.86	1.97	2.06	2.13	2.19	2.30	2.39	2.47	2.53
715 500		54	7	450 000	.398	1.41	1.49	1.56	1.62	1.67	1.75	1.81	1.87	1.92	.530	1.88	1.99	2.08	2.16	2.22	2.33	2.42	2.49	2.56
636 000		54	7	400 000	.448	1.43	1.52	1.58	1.64	1.69	1.77	1.84	1.89	1.94	.598	1.91	2.02	2.11	2.18	2.25	2.36	2.45	2.52	2.59
556 500		30	7	350 000	.503	1.44	1.52	1.59	1.65	1.69	1.78	1.84	1.90	1.95	.671	1.92	2.03	2.12	2.19	2.26	2.37	2.46	2.53	2.60
477 000		30	7	300 000	.587	1.47	1.55	1.62	1.68	1.72	1.81	1.87	1.93	1.98	.783	1.96	2.07	2.16	2.23	2.30	2.41	2.50	2.57	2.63
397 500		30	7	250 000	.704	1.51	1.59	1.66	1.71	1.76	1.84	1.91	1.96	2.01	.939	2.01	2.12	2.21	2.28	2.35	2.46	2.54	2.62	2.68
336 400		30	7	0 000	.833	1.54	1.62	1.69	1.74	1.79	1.87	1.94	2.00	2.04	1.11	2.05	2.16	2.25	2.32	2.39	2.50	2.59	2.66	2.73
266 800		26	7	000	1.05	1.60	1.68	1.75	1.80	1.85	1.93	2.00	2.05	2.10	1.40	2.13	2.24	2.33	2.40	2.47	2.57	2.66	2.74	2.80
211 600	0 000	6	1	00	1.39	1.88	1.96	2.03	2.09	2.14	2.22	2.28	2.34	2.39	1.86	2.51	2.62	2.71	2.78	2.85	2.96	3.05	3.12	3.18
167 806	000	6	1	0	1.74	1.91	2.00	2.06	2.12	2.17	2.25	2.31	2.37	2.42	2.32	2.55	2.66	2.75	2.82	2.89	3.00	3.09	3.16	3.22
133 077	00	6	1	1	2.16	1.95	2.03	2.09	2.15	2.20	2.28	2.35	2.40	2.45	2.87	2.59	2.70	2.79	2.87	2.93	3.04	3.13	3.20	3.27
105 535	0	6	1	2	2.68	1.98	2.06	2.13	2.18	2.23	2.31	2.38	2.43	2.48	3.57	2.64	2.74	2.83	2.91	2.97	3.08	3.17	3.24	3.31
83 693	1	6	1	3	3.36	2.01	2.09	2.16	2.22	2.26	2.35	2.41	2.47	2.52	4.48	2.68	2.79	2.88	2.95	3.02	3.13	3.22	3.29	3.35
66 371	2	6	1	4	4.23	2.04	2.12	2.19	2.25	2.30	2.38	2.44	2.50	2.55	5.64	2.72	2.83	2.92	3.00	3.06	3.17	3.26	3.33	3.40
52 635	3	6	1	5	5.33	2.07	2.16	2.22	2.28	2.33	2.41	2.48	2.53	2.58	7.10	2.77	2.87	2.96	3.04	3.10	3.21	3.30	3.37	3.44
41 741	4	6	1	6	6.71	2.11	2.19	2.26	2.31	2.36	2.44	2.51	2.56	2.61	8.95	2.81	2.92	3.01	3.08	3.15	3.25	3.34	3.42	3.48

Circular mils (aluminum)	A. W. G. B&S	Alum	Steel	Copper equivalent	5 MILES—8.05 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet	6 MILES—9.66 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet
1 033 500		54	7	650 000	.461	2.25	2.38	2.49	2.59	2.67	2.80	2.91	3.01	3.09	.553	2.69	2.86	2.99	3.10	3.20	3.36	3.50	3.61	3.71
954 000		54	7	600 000	.498	2.27	2.41	2.52	2.61	2.69	2.83	2.94	3.03	3.11	.598	2.72	2.89	3.02	3.13	3.23	3.39	3.52	3.64	3.73
874 500		54	7	550 000	.545	2.29	2.43	2.54	2.63	2.72	2.85	2.96	3.05	3.14	.653	2.75	2.92	3.05	3.16	3.26	3.42	3.55	3.66	3.76
795 000		54	7	500 000	.597	2.32	2.46	2.57	2.66	2.74	2.88	2.99	3.08	3.16	.716	2.79	2.95	3.08	3.19	3.29	3.45	3.59	3.70	3.80
715 500		54	7	450 000	.663	2.36	2.49	2.60	2.69	2.78	2.91	3.02	3.11	3.20	.796	2.83	2.99	3.12	3.23	3.33	3.49	3.63	3.74	3.83
636 000		54	7	400 000	.747	2.39	2.53	2.64	2.73	2.81	2.95	3.06	3.15	3.23	.896	2.87	3.03	3.16	3.28	3.37	3.54	3.67	3.78	3.88
556 500		30	7	350 000	.839	2.40	2.54	2.65	2.74	2.82	2.96	3.07	3.16	3.24	1.01	2.88	3.05	3.18	3.29	3.39	3.55	3.69	3.80	3.89
477 000		30	7	300 000	.979	2.45	2.59	2.70	2.79	2.87	3.01	3.12	3.21	3.29	1.17	2.94	3.11	3.24	3.35	3.45	3.61	3.74	3.85	3.95
397 500		30	7	250 000	1.17	2.51	2.65	2.76	2.85	2.93	3.07	3.18	3.27	3.35	1.41	3.02	3.18	3.31	3.42	3.52	3.68	3.82	3.93	4.02
336 400		30	7	0 000	1.39	2.57	2.70	2.81	2.91	2.99	3.12	3.23	3.33	3.41	1.67	3.08	3.24	3.38	3.49	3.58	3.75	3.88	3.99	4.09
266 800		26	7	000	1.75	2.66	2.80	2.91	3.00	3.08	3.22	3.33	3.42	3.50	2.10	3.19	3.36	3.49	3.60	3.70	3.86	4.00	4.11	4.20
211 600	0000	6	1	00	2.32	3.14	3.27	3.39	3.48	3.56	3.70	3.81	3.90	3.98	2.79	3.77	3.93	4.06	4.17	4.27	4.43	4.57	4.68	4.78
167 806	000	6	1	0	2.90	3.19	3.33	3.44	3.53	3.61	3.75	3.86	3.95	4.03	3.48	3.83	3.99	4.12	4.23	4.33	4.50	4.63	4.74	4.84
133 077	00	6	1	1	3.59	3.24	3.38	3.49	3.58	3.66	3.80	3.91	4.00	4.08	4.31	3.89	4.05	4.19	4.30	4.40	4.56	4.69	4.80	4.90
105 535	0	6	1	2	4.47	3.30	3.43	3.54	3.64	3.72	3.85	3.96	4.06	4.14	5.36	3.95	4.12	4.25	4.36	4.46	4.62	4.76	4.87	4.96
83 693	1	6	1	3	5.60	3.35	3.49	3.60	3.69	3.77	3.91	4.02	4.11	4.19	6.72	4.02	4.19	4.32	4.43	4.53	4.69	4.82	4.93	5.03
66 371	2	6	1	4	7.05	3.41	3.54	3.65	3.74	3.83	3.96	4.07	4.16	4.25	8.46	4.09	4.25	4.38	4.49	4.59	4.75	4.89	5.00	5.09
52 635	3	6	1	5	8.88	3.46	3.59	3.70	3.80	3.88	4.01	4.13	4.22	4.30	10.7	4.15	4.31	4.45	4.56	4.65	4.82	4.95	5.06	5.16
41 741	4	6	1	6	11.2	3.51	3.65	3.76	3.85	3.93	4.07	4.18	4.27	4.35	13.4	4.21	4.38	4.51	4.62	4.72	4.88	5.02	5.13	5.22

Circular mils (aluminum)	A. W. G. B&S	Alum	Steel	Copper equivalent	7 MILES—11.27 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet	8 MILES—12.87 Km.: R	2 feet	2.5 feet	3 feet	3.5 feet	4 feet	5 feet	6 feet	7 feet	8 feet
1 033 500		54	7	650 000	.646	3.14	3.33	3.49	3.62	3.73	3.92	4.08	4.21	4.32	.738	3.59	3.81	3.99	4.14	4.27	4.48	4.66	4.81	4.94
954 000		54	7	600 000	.698	3.18	3.37	3.52	3.66	3.77	3.96	4.11	4.24	4.36	.797	3.63	3.85	4.03	4.18	4.31	4.52	4.70	4.85	4.98
874 500		54	7	550 000	.762	3.21	3.40	3.56	3.69	3.80	3.99	4.15	4.28	4.39	.871	3.67	3.89	4.06	4.21	4.34	4.56	4.74	4.89	5.02
795 000		54	7	500 000	.835	3.25	3.44	3.60	3.73	3.84	4.03	4.19	4.32	4.43	.954	3.72	3.93	4.11	4.26	4.39	4.61	4.78	4.93	5.06
715 500		54	7	450 000	.928	3.30	3.49	3.64	3.77	3.88	4.08	4.23	4.36	4.47	1.06	3.77	3.98	4.16	4.31	4.44	4.66	4.83	4.98	5.11
636 000		54	7	400 000	1.05	3.35	3.54	3.69	3.82	3.94	4.13	4.28	4.41	4.52	1.20	3.82	4.04	4.22	4.37	4.50	4.71	4.89	5.04	5.17
556 500		30	7	350 000	1.17	3.37	3.56	3.71	3.84	3.95	4.14	4.30	4.43	4.54	1.34	3.85	4.06	4.24	4.39	4.52	4.74	4.91	5.06	5.19
477 000		30	7	300 000	1.37	3.43	3.62	3.78	3.91	4.02	4.21	4.37	4.50	4.61	1.57	3.92	4.14	4.32	4.47	4.60	4.81	4.99	5.14	5.27
397 500		30	7	250 000	1.64	3.52	3.71	3.86	3.99	4.11	4.30	4.45	4.58	4.70	1.88	4.02	4.24	4.42	4.56	4.69	4.91	5.09	5.24	5.37
336 400		30	7	0 000	1.94	3.59	3.78	3.94	4.07	4.18	4.37	4.53	4.66	4.77	2.22	4.11	4.32	4.50	4.65	4.78	4.99	5.17	5.32	5.45
266 800		26	7	000	2.45	3.73	3.92	4.07	4.20	4.32	4.51	4.66	4.79	4.90	2.80	4.26	4.48	4.65	4.80	4.93	5.15	5.33	5.47	5.60
211 600	0000	6	1	00	3.25	4.39	4.58	4.74	4.87	4.98	5.17	5.33	5.46	5.57	3.71	5.02	5.24	5.42	5.57	5.69	5.91	6.09	6.24	6.37
167 806	000	6	1	0	4.06	4.47	4.66	4.81	4.94	5.05	5.24	5.40	5.53	5.64	4.64	5.10	5.32	5.50	5.65	5.78	5.99	6.17	6.32	6.45
133 077	00	6	1	1	5.03	4.54	4.73	4.89	5.01	5.13	5.32	5.47	5.60	5.72	5.75	5.19	5.41	5.58	5.73	5.86	6.08	6.26	6.40	6.53
105 535	0	6	1	2	6.25	4.61	4.80	4.96	5.09	5.20	5.39	5.55	5.68	5.79	7.15	5.27	5.49	5.67	5.82	5.95	6.16	6.34	6.49	6.62
83 693	1	6	1	3	7.84	4.69	4.88	5.04	5.17	5.28	5.47	5.63	5.76	5.87	8.96	5.36	5.58	5.76	5.91	6.04	6.25	6.43	6.58	6.71
66 371	2	6	1	4	9.87	4.77	4.96	5.11	5.24	5.35	5.55	5.70	5.83	5.94	11.3	5.45	5.66	5.84	5.99	6.12	6.34	6.51	6.66	6.79
52 635	3	6	1	5	12.4	4.84	5.03	5.19	5.32	5.43	5.62	5.77	5.90	6.02	14.2	5.53	5.75	5.93	6.07	6.20	6.42	6.60	6.75	6.88
41 741	4	6	1	6	15.7	4.92	5.11	5.26	5.39	5.51	5.70	5.85	5.98	6.09	17.9	5.62	5.84	6.01	6.16	6.29	6.51	6.69	6.83	6.96

These 60 cycle resistances are based upon a temperature of 25° C. (77° F.) and a current density of 600 amperes per square inch as given in table VI. The reactances are based upon all current densities for the multiple layer conductors and upon 600 amperes per square inch for the single layer conductors as given in table XII.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XXVII—TOTAL 60 CYCLE RESISTANCE AND TOTAL 60 CYCLE REACTANCE

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

9 MILES—14.48 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet 0.6 M	2.5 Feet 0.76 M	3 Feet 0.91 M	3.5 Feet 1.07 M	4 Feet 1.22 M	5 Feet 1.52 M	6 Feet 1.83 M	7 Feet 2.13 M	8 Feet 2.44 M
650 000		.841	4.59	4.83	5.03	5.20	5.35	5.59	5.79	5.96	6.11
600 000		.906	4.64	4.89	5.09	5.25	5.40	5.64	5.84	6.01	6.16
550 000		.984	4.69	4.93	5.13	5.30	5.45	5.69	5.89	6.06	6.20
500 000		1.08	4.74	4.99	5.18	5.35	5.50	5.74	5.94	6.11	6.26
450 000		1.19	4.80	5.04	5.24	5.41	5.56	5.80	6.00	6.17	6.31
400 000		1.34	4.88	5.13	5.32	5.49	5.64	5.88	6.08	6.25	6.40
350 000		1.52	4.96	5.20	5.40	5.57	5.71	5.95	6.15	6.32	6.47
300 000		1.77	5.04	5.28	5.48	5.65	5.80	6.04	6.24	6.41	6.55
250 000		2.12	5.14	5.38	5.58	5.75	5.90	6.14	6.34	6.51	6.65
211 600	0000	2.50	5.29	5.53	5.73	5.90	6.05	6.29	6.49	6.66	6.80
167 806	000	3.15	5.42	5.66	5.86	6.03	6.17	6.42	6.62	6.78	6.93
133 077	00	3.96	5.54	5.79	5.99	6.15	6.30	6.54	6.74	6.91	7.06
105 535	0	4.99	5.67	5.91	6.11	6.28	6.43	6.67	6.87	7.04	7.18
83 693	1	6.30	5.80	6.04	6.24	6.41	6.55	6.80	7.00	7.16	7.31
66 371	2	7.94	5.92	6.17	6.37	6.53	6.68	6.92	7.12	7.29	7.44
52 635	3	10.1	6.05	6.29	6.49	6.66	6.81	7.05	7.25	7.42	7.56
41 741	4	12.6	6.18	6.42	6.62	6.79	6.93	7.18	7.38	7.54	7.69
33 102	5	15.9	6.30	6.55	6.75	6.91	7.06	7.30	7.50	7.67	7.82
26 251	6	20.1	6.43	6.67	6.87	7.04	7.19	7.43	7.63	7.80	7.94

10 MILES—16.09 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet 0.61 M	2.5 Feet 0.76 M	3 Feet 0.91 M	3.5 Feet 1.07 M	4 Feet 1.22 M	5 Feet 1.52 M	6 Feet 1.83 M	7 Feet 2.13 M	8 Feet 2.44 M
650 000		.934	5.10	5.37	5.59	5.78	5.94	6.21	6.43	6.62	6.78
600 000		1.01	5.16	5.43	5.65	5.84	6.00	6.27	6.49	6.68	6.84
550 000		1.09	5.21	5.48	5.70	5.89	6.05	6.32	6.54	6.73	6.89
500 000		1.20	5.27	5.54	5.76	5.95	6.11	6.38	6.60	6.79	6.95
450 000		1.32	5.33	5.60	5.82	6.01	6.17	6.44	6.67	6.85	7.01
400 000		1.48	5.42	5.69	5.92	6.10	6.27	6.54	6.76	6.94	7.11
350 000		1.69	5.51	5.78	6.00	6.18	6.35	6.62	6.84	7.03	7.19
300 000		1.97	5.60	5.87	6.09	6.28	6.44	6.71	6.93	7.12	7.28
250 000		2.35	5.71	5.98	6.20	6.39	6.55	6.82	7.04	7.23	7.39
211 600	0000	2.78	5.88	6.15	6.37	6.56	6.72	6.99	7.21	7.40	7.56
167 806	000	3.50	6.02	6.29	6.51	6.70	6.86	7.13	7.35	7.54	7.70
133 077	00	4.40	6.16	6.43	6.65	6.84	7.00	7.27	7.49	7.68	7.84
105 535	0	5.55	6.30	6.57	6.79	6.98	7.14	7.41	7.63	7.82	7.98
83 693	1	7.00	6.44	6.71	6.93	7.12	7.28	7.55	7.77	7.96	8.12
66 371	2	8.82	6.58	6.85	7.07	7.26	7.42	7.69	7.91	8.10	8.26
52 635	3	11.1	6.72	6.99	7.21	7.40	7.56	7.83	8.05	8.24	8.40
41 741	4	14.0	6.86	7.13	7.35	7.54	7.70	7.97	8.19	8.38	8.54
33 102	5	17.7	7.00	7.27	7.49	7.68	7.84	8.11	8.34	8.52	8.68
26 251	6	22.3	7.14	7.41	7.64	7.82	7.98	8.26	8.48	8.66	8.83

11 MILES—17.70 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.03	5.61	5.91	6.15	6.36	6.54	6.83	7.08	7.28	7.46
600 000		1.11	5.67	5.97	6.22	6.42	6.60	6.90	7.14	7.35	7.52
550 000		1.20	5.73	6.03	6.27	6.48	6.66	6.95	7.20	7.40	7.58
500 000		1.32	5.80	6.09	6.34	6.54	6.72	7.02	7.26	7.47	7.65
450 000		1.46	5.87	6.16	6.41	6.61	6.79	7.09	7.33	7.54	7.72
400 000		1.63	5.97	6.26	6.51	6.71	6.89	7.19	7.43	7.64	7.82
350 000		1.86	6.06	6.35	6.60	6.80	6.98	7.28	7.52	7.73	7.91
300 000		2.16	6.16	6.46	6.70	6.91	7.08	7.38	7.62	7.83	8.01
250 000		2.59	6.28	6.58	6.82	7.03	7.21	7.50	7.75	7.95	8.13
211 600	0000	3.05	6.46	6.76	7.01	7.21	7.39	7.69	7.93	8.14	8.32
167 806	000	3.85	6.62	6.92	7.16	7.37	7.54	7.84	8.09	8.29	8.47
133 077	00	4.84	6.77	7.07	7.32	7.52	7.70	8.00	8.24	8.45	8.62
105 535	0	6.10	6.93	7.23	7.47	7.68	7.85	8.15	8.39	8.60	8.78
83 693	1	7.70	7.08	7.38	7.62	7.83	8.01	8.31	8.55	8.76	8.93
66 371	2	9.70	7.24	7.54	7.78	7.99	8.16	8.46	8.70	8.91	9.09
52 635	3	12.2	7.39	7.69	7.93	8.14	8.32	8.62	8.86	9.07	9.24
41 741	4	15.4	7.55	7.85	8.09	8.29	8.47	8.77	9.01	9.22	9.40
33 102	5	19.5	7.70	8.00	8.24	8.45	8.63	8.93	9.17	9.37	9.55
26 251	6	24.5	7.86	8.15	8.40	8.60	8.78	9.08	9.32	9.53	9.71

12 MILES—19.31 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.12	6.12	6.45	6.71	6.94	7.13	7.45	7.72	7.95	8.14
600 000		1.21	6.19	6.51	6.78	7.00	7.20	7.52	7.79	8.01	8.21
550 000		1.31	6.25	6.58	6.84	7.07	7.26	7.59	7.85	8.08	8.27
500 000		1.44	6.32	6.65	6.91	7.14	7.33	7.66	7.92	8.15	8.34
450 000		1.59	6.40	6.72	6.99	7.21	7.41	7.73	8.00	8.22	8.42
400 000		1.78	6.51	6.83	7.10	7.32	7.52	7.84	8.11	8.33	8.53
350 000		2.03	6.61	6.93	7.20	7.42	7.62	7.94	8.21	8.43	8.62
300 000		2.36	6.72	7.04	7.31	7.53	7.73	8.05	8.32	8.54	8.74
250 000		2.83	6.85	7.18	7.44	7.67	7.86	8.18	8.45	8.68	8.87
211 600	0000	3.33	7.05	7.38	7.64	7.87	8.06	8.39	8.65	8.88	9.07
167 806	000	4.19	7.22	7.55	7.81	8.04	8.23	8.56	8.82	9.04	9.24
133 077	00	5.28	7.39	7.72	7.98	8.20	8.40	8.72	8.99	9.21	9.41
105 535	0	6.66	7.56	7.88	8.15	8.37	8.57	8.89	9.16	9.38	9.58
83 693	1	8.39	7.73	8.05	8.32	8.54	8.74	9.06	9.33	9.55	9.75
66 371	2	10.6	7.90	8.22	8.49	8.71	8.91	9.23	9.50	9.72	9.91
52 635	3	13.3	8.07	8.39	8.66	8.88	9.07	9.40	9.67	9.89	10.1
41 741	4	16.8	8.23	8.56	8.82	9.05	9.24	9.57	9.83	10.1	10.3
33 102	5	21.2	8.40	8.73	8.99	9.22	9.41	9.74	10.0	10.2	10.4
26 251	6	26.8	8.57	8.90	9.16	9.39	9.58	9.91	10.2	10.4	10.6

13 MILES—20.92 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.22	6.63	6.98	7.27	7.51	7.73	8.08	8.36	8.61	8.82
600 000		1.31	6.71	7.06	7.35	7.59	7.80	8.15	8.44	8.68	8.89
550 000		1.42	6.77	7.13	7.41	7.66	7.87	8.22	8.51	8.75	8.96
500 000		1.56	6.85	7.20	7.49	7.73	7.94	8.29	8.58	8.82	9.04
450 000		1.72	6.93	7.28	7.57	7.81	8.03	8.38	8.67	8.91	9.12
400 000		1.93	7.05	7.40	7.69	7.93	8.15	8.50	8.78	9.03	9.24
350 000		2.20	7.16	7.51	7.80	8.04	8.25	8.60	8.89	9.13	9.34
300 000		2.56	7.28	7.63	7.92	8.16	8.37	8.72	9.01	9.25	9.46
250 000		3.06	7.42	7.77	8.06	8.30	8.52	8.87	9.16	9.40	9.61
211 600	0000	3.61	7.64	7.99	8.28	8.52	8.73	9.08	9.37	9.62	9.83
167 806	000	4.54	7.82	8.17	8.46	8.71	8.92	9.27	9.56	9.80	10.0
133 077	00	5.72	8.01	8.36	8.65	8.89	9.10	9.45	9.74	9.98	10.2
105 535	0	7.21	8.19	8.54	8.83	9.07	9.28	9.63	9.92	10.2	10.4
83 693	1	9.09	8.37	8.72	9.01	9.25	9.46	9.82	10.1	10.4	10.6
66 371	2	11.5	8.55	8.91	9.19	9.44	9.65	10.0	10.3	10.5	10.7
52 635	3	14.5	8.74	9.09	9.38	9.62	9.83	10.2	10.5	10.7	10.9
41 741	4	18.2	8.92	9.27	9.56	9.80	10.0	10.4	10.7	10.9	11.1
33 102	5	23.0	9.10	9.46	9.74	9.99	10.2	10.6	10.8	11.1	11.3
26 251	6	29.0	9.29	9.64	9.93	10.2	10.4	10.7	11.0	11.3	11.5

14 MILES—22.53 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.31	7.14	7.52	7.83	8.09	8.32	8.70	9.01	9.27	9.50
600 000		1.41	7.22	7.60	7.91	8.17	8.40	8.78	9.09	9.35	9.58
550 000		1.53	7.29	7.67	7.98	8.25	8.47	8.85	9.16	9.42	9.65
500 000		1.68	7.38	7.76	8.06	8.33	8.55	8.93	9.24	9.50	9.73
450 000		1.85	7.47	7.84	8.15	8.42	8.64	9.02	9.33	9.59	9.82
400 000		2.08	7.59	7.97	8.28	8.54	8.77	9.15	9.46	9.72	9.95
350 000		2.37	7.71	8.09	8.40	8.66	8.88	9.26	9.57	9.84	10.1
300 000		2.75	7.84	8.22	8.53	8.79	9.02	9.39	9.70	9.97	10.2
250 000		3.30	7.99	8.37	8.68	8.94	9.17	9.55	9.86	10.1	10.4
211 600	0000	3.89	8.23	8.61	8.92	9.18	9.41	9.78	10.1	10.4	10.6
167 806	000	4.89	8.42	8.80	9.11	9.37	9.60	9.98	10.3	10.6	10.8
133 077	00	6.16	8.62	9.00	9.31	9.57	9.80	10.2	10.5	10.8	11.0
105 535	0	7.77	8.82	9.20	9.51	9.77	10.0	10.4	10.7	11.0	11.2
83 693	1	9.79	9.02	9.39	9.70	9.97	10.2	10.6	10.9	11.1	11.4
66 371	2	12.4	9.21	9.59	9.90	10.2	10.4	10.8	11.1	11.3	11.6
52 635	3	15.6	9.41	9.79	10.1	10.4	10.6	11.0	11.3	11.5	11.8
41 741	4	19.6	9.61	9.99	10.3	10.6	10.8	11.2	11.5	11.7	12.0
33 102	5	24.8	9.80	10.2	10.5	10.8	11.0	11.4	11.7	11.9	12.2
26 251	6	31.2	10.0	10.4	10.7	11.0	11.2	11.6	11.9	12.1	12.4

15 MILES—24.14 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.40	7.65	8.06	8.39	8.67	8.91	9.32	9.65	9.93	10.2
600 000		1.51	7.74	8.14	8.48	8.76	9.00	9.40	9.74	10.0	10.3
550 000		1.64	7.82	8.22	8.55	8.83	9.08	9.48	9.82	10.1	10.3
500 000		1.80	7.90	8.31	8.64	8.92	9.16	9.57	9.90	10.2	10.4
450 000		1.99	8.00	8.41	8.74	9.02	9.26	9.67	10.0	10.3	10.5
400 000		2.23	8.14	8.54	8.87	9.16	9.40	9.80	10.1	10.4	10.7
350 000		2.54	8.26	8.66	9.00	9.28	9.52	9.92	10.3	10.5	10.8
300 000		2.95	8.40	8.80	9.14	9.42	9.66	10.1	10.4	10.7	10.9
250 000		3.53	8.56	8.97	9.30	9.58	9.83	10.2	10.6	10.8	11.1
211 600	0000	4.16	8.81	9.22	9.55	9.83	10.1	10.5	10.8	11.1	11.3
167 806	000	5.24	9.03	9.43	9.76	10.0	10.3	10.7	11.0	11.3	11.6
133 077	00	6.61	9.24	9.64	9.98	10.3	10.5	10.9	11.2	11.5	11.8
105 535	0	8.32	9.45	9.85	10.2	10.5	10.7	11.1	11.5	11.7	12.0
83 693	1	10.5	9.66	10.1	10.4	10.7	10.9	11.3	11.7	11.9	12.2
66 371	2	13.2	9.87	10.3	10.6	10.9	11.1	11.5	11.9	12.2	12.4
52 635	3	16.7	10.1	10.5	10.8	11.1	11.3	11.8	12.1	12.4	12.6
41 741	4	21.0	10.3	10.7	11.0	11.3	11.6	12.0	12.3	12.6	12.8
33 102	5	26.5	10.5	10.9	11.2	11.5	11.8	12.2	12.5	12.8	13.0
26 251	6	33.4	10.7	11.1	11.5	11.7	12.0	12.4	12.7	13.0	13.2

16 MILES—25.75 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
650 000		1.50	8.16	8.59	8.95	9.25	9.51	9.94	10.3	10.6	10.9
600 000		1.61	8.25	8.69	9.04	9.34	9.60	10.0	10.4	10.7	10.9
550 000		1.75	8.34	8.77	9.12	9.42	9.68	10.1	10.5	10.8	11.0
500 000		1.92	8.43	8.86	9.22	9.52	9.77	10.2	10.6	10.9	11.1
450 000		2.12	8.53	8.97	9.32	9.62	9.88	10.3	10.7	11.0	11.2
400 000		2.37	8.68	9.11	9.47	9.77	10.0	10.5	10.8	11.1	11.4
350 000		2.70	8.81	9.24	9.60	9.89	10.2	10.6	10.9	11.2	11.5
300 000		3.15	8.96	9.39	9.74	10.0	10.3	10.7	11.1	11.4	11.7
250 000		3.77	9.13	9.57	9.92	10.2	10.5	10.9	11.3	11.6	11.8
211 600	0000	4.44	9.40	9.84	10.2	10.5	10.8	11.2	11.5	11.8	12.1
167 806	000	5.59	9.63	10.1	10.4	10.7	11.0	11.4	11.8	12.1	12.3
133 077	00	7.05	9.85	10.3	10.6	10.9	11.2	11.6	12.0	12.3	12.5
105 535	0	8.88	10.1	10.5	10.9	11.2	11.4	11.9	12.2	12.5	12.8
83 693	1	11.2	10.3	10.7	11.1	11.4	11.7	12.1	12.4	12.7	13.0
66 371	2	14.1	10.5	11.0	11.3	11.6	11.9	12.3	12.7	13.0	13.2
52 635	3	17.8	10.8	11.2	11.5	11.8	12.1	12.5	12.9	13.2	13.4
41 741	4	22.4	11.0	11.4	11.8	12.1	12.3	12.8	13.1	13.4	13.7
33 102	5	28.3	11.2	11.6	12.0	12.3	12.6	13.0	13.3	13.6	13.9
26 251	6	35.7	11.4	11.9	12.2	12.5	12.8	13.2	13.6	13.9	14.1

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

★ These 60 cycle resistances are for hard drawn copper at 25° C. (77° F.)

TABLE XXVIII—TOTAL 60 CYCLE RESISTANCE AND 60 CYCLE REACTANCE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — NUMBER OF WIRES — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

Circular Mils (Aluminum)	American Wire Gauge B&S	Alum	Steel	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin. 61%	9 MILES—14.48 KM. Total Resistance R	Total Reactance X for Spacings D: 2 Feet 0.61 M.	2.5 Feet 0.76 M.	3 Feet 0.91 M.	3.5 Feet 1.07 M.	4 Feet 1.22 M.	5 Feet 1.52 M.	6 Feet 1.83 M.	7 Feet 2.13 M.	8 Feet 2.44 M.	10 MILES—16.09 KM. Total Resistance R	Total Reactance X for Spacings D: 2 Feet 0.61 M.	2.5 Feet 0.76 M.	3 Feet 0.91 M.	3.5 Feet 1.07 M.	4 Feet 1.22 M.	5 Feet 1.52 M.	6 Feet 1.83 M.	7 Feet 2.13 M.	8 Feet 2.44 M.
1 033 500		54	7	650 000	.830	4.04	4.29	4.49	4.65	4.80	5.04	5.24	5.41	5.56	.922	4.49	4.76	4.98	5.17	5.33	5.60	5.83	6.01	6.18
954 000		54	7	600 000	.897	4.09	4.33	4.53	4.70	4.85	5.09	5.29	5.46	5.60	.997	4.54	4.81	5.03	5.22	5.38	5.65	5.87	6.06	6.22
874 500		54	7	550 000	.980	4.13	4.37	4.57	4.74	4.89	5.13	5.33	5.50	5.64	1.09	4.59	4.86	5.08	5.27	5.43	5.70	5.92	6.11	6.27
795 000		54	7	500 000	1.07	4.18	4.42	4.63	4.79	4.94	5.18	5.38	5.55	5.69	1.19	4.65	4.92	5.14	5.32	5.49	5.76	5.98	6.16	6.33
715 500		54	7	450 000	1.19	4.24	4.48	4.68	4.85	4.99	5.24	5.44	5.61	5.75	1.33	4.71	4.98	5.20	5.39	5.55	5.82	6.04	6.23	6.39
636 000		54	7	400 000	1.35	4.30	4.55	4.75	4.91	5.06	5.30	5.50	5.67	5.82	1.49	4.78	5.05	5.27	5.46	5.62	5.89	6.12	6.30	6.46
556 500		30	7	350 000	1.51	4.33	4.57	4.77	4.94	5.08	5.33	5.53	5.69	5.84	1.68	4.81	5.08	5.30	5.49	5.65	5.92	6.14	6.33	6.49
477 000		30	7	300 000	1.76	4.42	4.66	4.86	5.03	5.17	5.42	5.62	5.78	5.93	1.96	4.91	5.18	5.40	5.58	5.75	6.02	6.24	6.42	6.59
397 500		30	7	250 000	2.11	4.52	4.77	4.97	5.13	5.28	5.52	5.72	5.89	6.04	2.35	5.03	5.30	5.52	5.70	5.87	6.14	6.36	6.55	6.71
336 400		30	7	0000	2.50	4.62	4.86	5.06	5.23	5.38	5.62	5.82	5.99	6.13	2.78	5.13	5.40	5.63	5.81	5.97	6.24	6.47	6.65	6.81
266 800		26	7	000	3.15	4.79	5.04	5.24	5.40	5.55	5.79	5.99	6.16	6.31	3.50	5.32	5.60	5.82	6.00	6.16	6.44	6.66	6.84	7.01
211 600	0 000	6	1	00	4.18	5.65	5.89	6.09	6.26	6.41	6.65	6.85	7.02	7.16	4.64	6.28	6.55	6.77	6.96	7.12	7.39	7.61	7.80	7.96
167 806	000	6	1	0	5.22	5.74	5.99	6.19	6.35	6.50	6.74	6.94	7.11	7.25	5.79	6.38	6.65	6.87	7.06	7.22	7.49	7.71	7.90	8.06
133 077	00	6	1	1	6.47	5.84	6.08	6.28	6.45	6.59	6.84	7.04	7.20	7.35	7.18	6.48	6.76	6.98	7.16	7.33	7.60	7.82	8.00	8.17
105 535	0	6	1	2	8.04	5.93	6.18	6.38	6.54	6.69	6.93	7.13	7.30	7.44	8.93	6.59	6.86	7.08	7.27	7.43	7.70	7.93	8.11	8.27
83 693	1	6	1	3	10.1	6.03	6.28	6.48	6.64	6.79	7.03	7.23	7.40	7.55	11.2	6.70	6.98	7.20	7.38	7.54	7.82	8.04	8.22	8.38
66 371	2	6	1	4	12.7	6.13	6.37	6.57	6.74	6.88	7.13	7.33	7.50	7.64	14.1	6.81	7.08	7.30	7.49	7.65	7.92	8.14	8.33	8.49
52 635	3	6	1	5	16.0	6.22	6.47	6.67	6.83	6.98	7.22	7.42	7.59	7.74	17.8	6.91	7.19	7.41	7.59	7.76	8.03	8.25	8.43	8.60
41 741	4	6	1	6	20.1	6.32	6.57	6.77	6.93	7.08	7.32	7.52	7.69	7.84	22.4	7.02	7.30	7.52	7.70	7.86	8.14	8.36	8.54	8.71

Circular Mils (Aluminum)	American Wire Gauge B&S	Alum	Steel	Copper Equivalent	11 MILES—17.70 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	12 MILES—19.31 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
1 033 500		54	7	650 000	1.02	4.94	5.24	5.48	5.69	5.86	6.16	6.41	6.61	6.79	1.11	5.39	5.71	5.98	6.20	6.40	6.72	6.99	7.22	7.41
954 000		54	7	600 000	1.10	4.99	5.29	5.54	5.74	5.92	6.22	6.46	6.67	6.85	1.20	5.45	5.77	6.04	6.27	6.46	6.78	7.05	7.27	7.47
874 500		54	7	550 000	1.20	5.05	5.35	5.59	5.79	5.97	6.27	6.52	6.72	6.90	1.31	5.51	5.83	6.09	6.32	6.51	6.84	7.11	7.33	7.52
795 000		54	7	500 000	1.31	5.11	5.41	5.65	5.86	6.03	6.33	6.58	6.78	6.96	1.43	5.57	5.90	6.17	6.39	6.58	6.91	7.18	7.40	7.59
715 500		54	7	450 000	1.46	5.18	5.48	5.72	5.93	6.10	6.40	6.65	6.85	7.03	1.59	5.65	5.98	6.24	6.46	6.66	6.99	7.25	7.47	7.67
636 000		54	7	400 000	1.64	5.26	5.56	5.80	6.01	6.18	6.48	6.73	6.93	7.11	1.79	5.74	6.06	6.33	6.55	6.75	7.07	7.34	7.56	7.75
556 500		30	7	350 000	1.85	5.29	5.59	5.83	6.03	6.21	6.51	6.76	6.96	7.14	2.01	5.77	6.09	6.36	6.58	6.78	7.10	7.37	7.59	7.79
477 000		30	7	300 000	2.15	5.40	5.69	5.94	6.14	6.32	6.62	6.86	7.07	7.25	2.35	5.89	6.21	6.48	6.70	6.89	7.22	7.49	7.71	7.90
397 500		30	7	250 000	2.58	5.53	5.83	6.07	6.27	6.45	6.75	7.00	7.20	7.38	2.82	6.03	6.36	6.62	6.85	7.04	7.37	7.63	7.85	8.05
336 400		30	7	0000	3.05	5.64	5.94	6.19	6.39	6.57	6.87	7.11	7.32	7.49	3.33	6.16	6.48	6.75	6.97	7.17	7.49	7.76	7.98	8.17
266 800		26	7	000	3.85	5.86	6.16	6.40	6.60	6.78	7.08	7.32	7.53	7.71	4.20	6.39	6.71	6.98	7.20	7.40	7.72	7.99	8.21	8.41
211 600	0000	6	1	00	5.11	6.91	7.20	7.45	7.65	7.83	8.13	8.37	8.58	8.75	5.57	7.53	7.86	8.13	8.35	8.54	8.87	9.13	9.36	9.55
167 806	000	6	1	0	6.37	7.02	7.32	7.56	7.76	7.94	8.24	8.48	8.69	8.87	6.95	7.66	7.98	8.25	8.47	8.66	8.99	9.26	9.48	9.67
133 077	00	6	1	1	7.90	7.13	7.43	7.68	7.88	8.06	8.36	8.60	8.80	8.98	8.62	7.78	8.11	8.37	8.60	8.79	9.12	9.38	9.61	9.80
105 535	0	6	1	2	9.83	7.25	7.55	7.79	8.00	8.17	8.47	8.72	8.92	9.10	10.7	7.91	8.23	8.50	8.72	8.92	9.24	9.51	9.73	9.93
83 693	1	6	1	3	12.3	7.37	7.67	7.92	8.12	8.30	8.60	8.84	9.04	9.22	13.4	8.04	8.37	8.64	8.86	9.05	9.38	9.65	9.87	10.1
66 371	2	6	1	4	15.5	7.49	7.79	8.03	8.24	8.41	8.71	8.96	9.16	9.34	16.9	8.17	8.50	8.76	8.98	9.18	9.51	9.77	9.99	10.2
52 635	3	6	1	5	19.5	7.61	7.91	8.15	8.35	8.53	8.83	9.07	9.28	9.46	21.3	8.30	8.62	8.89	9.11	9.31	9.63	9.90	10.1	10.3
41 741	4	6	1	6	24.6	7.73	8.03	8.27	8.47	8.65	8.95	9.19	9.40	9.58	26.8	8.43	8.75	9.02	9.24	9.44	9.76	10.0	10.3	10.5

Circular Mils (Aluminum)	American Wire Gauge B&S	Alum	Steel	Copper Equivalent	13 MILES—20.92 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	14 MILES—22.53 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
1 033 500		54	7	650 000	1.20	5.84	6.19	6.48	6.72	6.93	7.28	7.57	7.82	8.03	1.29	6.29	6.67	6.98	7.24	7.46	7.84	8.16	8.42	8.65
954 000		54	7	600 000	1.30	5.90	6.25	6.54	6.79	7.00	7.35	7.64	7.88	8.09	1.40	6.36	6.74	7.05	7.31	7.54	7.91	8.22	8.49	8.71
874 500		54	7	550 000	1.42	5.96	6.32	6.60	6.85	7.06	7.41	7.70	7.94	8.15	1.53	6.42	6.80	7.11	7.37	7.60	7.98	8.29	8.55	8.78
795 000		54	7	500 000	1.55	6.04	6.39	6.68	6.92	7.13	7.48	7.77	8.01	8.22	1.67	6.50	6.88	7.20	7.45	7.68	8.06	8.37	8.63	8.86
715 500		54	7	450 000	1.72	6.12	6.47	6.76	7.00	7.21	7.57	7.86	8.10	8.31	1.86	6.59	6.97	7.28	7.54	7.77	8.15	8.46	8.72	8.95
636 000		54	7	400 000	1.94	6.21	6.57	6.86	7.10	7.31	7.66	7.95	8.19	8.40	2.09	6.69	7.07	7.38	7.64	7.87	8.25	8.56	8.82	9.05
556 500		30	7	350 000	2.18	6.25	6.60	6.89	7.13	7.34	7.70	7.98	8.22	8.43	2.35	6.73	7.11	7.42	7.68	7.91	8.29	8.60	8.86	9.08
477 000		30	7	300 000	2.54	6.38	6.73	7.02	7.26	7.47	7.82	8.11	8.35	8.56	2.74	6.87	7.25	7.56	7.82	8.04	8.42	8.74	8.99	9.22
397 500		30	7	250 000	3.05	6.53	6.89	7.18	7.42	7.63	7.98	8.27	8.51	8.72	3.29	7.04	7.42	7.73	7.99	8.21	8.59	8.90	9.16	9.39
336 400		30	7	0000	3.61	6.67	7.02	7.31	7.55	7.76	8.12	8.41	8.65	8.86	3.89	7.18	7.56	7.88	8.13	8.36	8.74	9.05	9.31	9.54
266 800		26	7	000	4.55	6.92	7.27	7.56	7.80	8.01	8.37	8.66	8.90	9.11	4.90	7.45	7.83	8.14	8.40	8.63	9.01	9.32	9.58	9.81
211 600	0000	6	1	00	6.04	8.16	8.51	8.80	9.04	9.25	9.61	9.90	10.1	10.4	6.50	8.79	9.17	9.48	9.74	9.97	10.3	10.7	10.9	11.1
167 806	000	6	1	0	7.53	8.29	8.65	8.94	9.17	9.39	9.74	10.0	10.3	10.5	8.11	8.93	9.31	9.62	9.88	10.1	10.5	10.8	11.1	11.3
133 077	00	6	1	1	9.34	8.43	8.78	9.07	9.31	9.52	9.88	10.2	10.4	10.6	10.1	9.08	9.46	9.77	10.0	10.3	10.6	11.0	11.2	11.4
105 535	0	6	1	2	11.6	8.57	8.92	9.21	9.45	9.66	10.0	10.3	10.5	10.8	12.5	9.23	9.61	9.92	10.2	10.4	10.8	11.1	11.4	11.6
83 693	1	6	1	3	14.6	8.71	9.07	9.36	9.60	9.81	10.2	10.5	10.7	10.9	15.7	9.38	9.77	10.1	10.3	10.6	10.9	11.3	11.5	11.7
66 371	2	6	1	4	18.3	8.85	9.20	9.49	9.73	9.94	10.3	10.6	10.8	11.0	19.7	9.53	9.91	10.2	10.5	10.7	11.1	11.4	11.7	11.9
52 635	3	6	1	5	23.1	8.99	9.34	9.63	9.87	10.1	10.4	10.7	11.0	11.2	24.9	9.68	10.1	10.4	10.6	10.9	11.2	11.6	11.8	12.0
41 741	4	6	1	6	29.1	9.13	9.48	9.77	10.0	10.2	10.6	10.9	11.1	11.3	31.3	9.83	10.2	10.5	10.8	11.0	11.4	11.7	12.0	12.2

Circular Mils (Aluminum)	American Wire Gauge B&S	Alum	Steel	Copper Equivalent	15 MILES—24.14 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet	16 MILES—25.75 KM. R	2 Feet	2.5 Feet	3 Feet	3.5 Feet	4 Feet	5 Feet	6 Feet	7 Feet	8 Feet
1 033 500		54	7	650 000	1.38	6.74	7.14	7.48	7.75	8.00	8.40	8.74	9.07	9.26	1.48	7.18	7.62	7.97	8.27	8.53	8.96	9.32	9.62	9.88
954 000		54	7	600 000	1.50	6.81	7.22	7.55	7.83	8.08	8.48	8.81	9.09	9.34	1.59	7.26	7.70	8.05	8.35	8.61	9.04	9.40	9.70	9.96
874 500		54	7	550 000	1.63	6.88	7.29	7.62	7.90	8.14	8.55	8.89	9.16	9.41	1.74	7.34	7.78	8.13	8.43	8.69	9.12	9.48	9.77	10.0
795 000		54	7	500 000	1.79	6.97	7.37	7.71	7.99	8.23	8.64	8.97	9.25	9.49	1.91	7.43	7.87	8.22	8.52	8.78	9.21	9.57	9.86	10.1
715 500		54	7	450 000	1.99	7.06	7.47	7.81	8.08	8.32	8.73	9.07	9.34	9.59	2.12	7.53	7.97	8.33	8.62	8.88	9.31	9.67	9.97	10.2
636 000		54	7	400 000	2.24	7.17	7.58	7.91	8.19	8.43	8.84	9.17	9.45	9.69	2.39	7.65	8.08	8.44	8.73	8.99	9.43	9.78	10.1	10.3
556 500		30	7	350 000	2.52	7.21	7.62	7.95	8.23	8.47	8.88	9.21	9.49	9.73	2.68	7.69	8.13	8.48	8.78	9.04	9.47	9.83	10.1	10.4
477 000		30	7	300 000	2.94	7.36	7.76	8.10	8.38	8.62	9.03	9.36	9.64	9.88	3.13	7.85	8.28	8.64	8.93	9.19	9.63	9.98	10.3	10.5
397 500		30	7	250 000	3.52	7.54	7.95	8.28	8.56	8.80	9.21	9.54	9.82	10.1	3.76	8.04	8.48	8.83	9.13	9.39	9.82	10.2	10.5	10.7
336 400		30	7	0 000	4.16	7.70	8.10	8.44	8.72	8.96	9.37	9.70	9.98	10.2	4.44	8.21	8.64	9.00	9.30	9.56	9.99	10.4	10.6	10.9
266 800		26	7	000	5.25	7.99	8.39	8.73	9.00	9.25	9.65	9.99	10.3	10.5	5.60	8.52	8.95	9.31	9.60	9.86	10.3	10.7	11.0	11.2
211 600	0 000	6	1	00	6.96	9.42	9.82	10.2	10.4	10.7	11.1	11.4	11.7	11.9	7.43	10.0	10.5	10.8	11.1	11.4	11.8	12.2	12.5	12.7
167 806	000	6	1	0	8.69	9.57	9.98	10.3	10.6	10.8	11.2	11.6	11.9	12.1	9.27	10.2	10.6	11.0	11.3	11.6	12.0	12.3	12.6	12.9
133 077	00	6	1	1	10.8	9.73	10.1	10.5	10.7	11.0	11.4	11.7	12.0	12.3	11.5	10.4	10.8	11.2	11.5	11.7	12.2	12.5	12.8	13.1
105 535	0	6	1	2	13.4	9.89	10.3	10.6	10.9	11.2	11.6	11.9	12.2	12.4	14.3	10.5	11.0	11.3	11.6	11.9	12.3	12.7	13.0	13.2
83 693	1	6	1	3	16.8	10.1	10.5	10.8	11.1	11.3	11.7	12.1	12.3	12.6	17.9	10.7	11.2	11.5	11.8	12.1	12.5	12.9	13.2	13.4
66 371	2	6	1	4	21.2	10.2	10.6	11.0	11.2	11.5	11.9	12.2	12.5	12.7	22.6	10.9	11.3	11.7	12.0	12.2	12.7	13.0	13.3	13.6
52 635	3	6	1	5	26.6	10.4	10.8	11.1	11.4	11.6	12.0	12.4	12.7	12.9	28.4	11.1	11.5	11.9	12.2	12.4	12.8	13.2	13.5	13.8
41 741	4	6	1	6	33.6	10.5	10.9	11.3	11.6	11.8	12.2	12.5	12.8	13.1	35.8	11.2	11.7	12.0	12.3	12.6	13.0	13.4	13.7	13.9

These 60 cycle resistances are based upon a temperature of 25° C. (77° F.) and a current density of 600 amperes per square inch as given in table VI. The reactances are based upon all current densities for the multiple layer conductors and upon 600 amperes per square inch for the single layer conductors as given in table XII.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XXIX—TOTAL 60 CYCLE RESISTANCE AND TOTAL 60 CYCLE REACTANCE

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

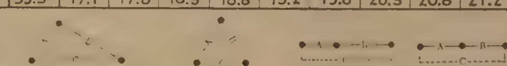
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	17 MILES—27.36 Km.										18 MILES—28.97 Km.									
		TOTAL RESISTANCE R ★	TOTAL REACTANCE X									TOTAL RESISTANCE R ★	TOTAL REACTANCE X								
			2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)		2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)
650 000		1.59	8.67	9.13	9.51	9.83	10.1	10.6	10.9	11.3	11.5	1.68	9.18	9.67	10.1	10.4	10.7	11.2	11.6	11.9	12.2
600 000		1.71	8.77	9.23	9.61	9.92	10.2	10.7	11.0	11.4	11.6	1.81	9.28	9.77	10.2	10.5	10.8	11.3	11.7	12.0	12.3
550 000		1.86	8.86	9.32	9.69	10.0	10.3	10.8	11.1	11.4	11.7	1.97	9.38	9.87	10.3	10.6	10.9	11.4	11.8	12.1	12.4
500 000		2.04	8.96	9.42	9.79	10.1	10.4	10.9	11.2	11.5	11.8	2.16	9.48	9.97	10.4	10.7	11.0	11.5	11.9	12.2	12.5
450 000		2.25	9.06	9.53	9.90	10.2	10.5	11.0	11.3	11.7	11.9	2.38	9.60	10.1	10.5	10.8	11.1	11.6	12.0	12.3	12.6
400 000		2.52	9.22	9.68	10.1	10.4	10.7	11.1	11.5	11.8	12.1	2.67	9.76	10.3	10.7	11.0	11.3	11.8	12.2	12.5	12.8
350 000		2.87	9.36	9.82	10.2	10.5	10.8	11.3	11.6	11.9	12.2	3.04	9.91	10.4	10.8	11.1	11.4	11.9	12.3	12.7	12.9
300 000		3.34	9.52	9.98	10.4	10.7	11.0	11.4	11.8	12.1	12.4	3.54	10.1	10.6	11.0	11.3	11.6	12.1	12.5	12.8	13.1
250 000		4.00	9.71	10.2	10.5	10.9	11.1	11.6	12.0	12.3	12.6	4.24	10.3	10.8	11.2	11.5	11.8	12.3	12.7	13.0	13.3
211 600	0000	4.72	9.99	10.5	10.8	11.2	11.4	11.9	12.3	12.6	12.9	5.00	10.6	11.1	11.5	11.8	12.1	12.6	13.0	13.3	13.6
167 806	000	5.94	10.2	10.7	11.1	11.4	11.7	12.1	12.5	12.8	13.1	6.29	10.8	11.3	11.7	12.1	12.3	12.8	13.2	13.6	13.9
133 077	00	7.49	10.5	10.9	11.3	11.6	11.9	12.4	12.7	13.1	13.3	7.93	11.1	11.6	12.0	12.3	12.6	13.1	13.5	13.8	14.1
105 535	0	9.43	10.7	11.2	11.5	11.9	12.1	12.6	13.0	13.3	13.6	9.99	11.3	11.8	12.2	12.6	12.9	13.3	13.7	14.1	14.4
83 693	1	11.9	11.0	11.4	11.8	12.1	12.4	12.8	13.2	13.5	13.8	12.6	11.6	12.1	12.5	12.8	13.1	13.6	14.0	14.3	14.6
66 371	2	15.0	11.2	11.7	12.0	12.3	12.6	13.1	13.5	13.8	14.1	15.9	11.8	12.3	12.7	13.1	13.4	13.9	14.2	14.6	14.9
52 635	3	18.9	11.4	11.9	12.3	12.6	12.9	13.3	13.7	14.0	14.3	20.0	12.1	12.6	13.0	13.3	13.6	14.1	14.5	14.8	15.1
41 741	4	23.8	11.7	12.1	12.5	12.8	13.1	13.6	13.9	14.3	14.5	25.2	12.4	12.8	13.2	13.6	13.9	14.4	14.8	15.1	15.4
33 102	5	30.1	11.9	12.4	12.7	13.1	13.3	13.8	14.2	14.5	14.8	31.8	12.6	13.1	13.5	13.8	14.1	14.6	15.0	15.3	15.6
26 251	6	37.9	12.1	12.6	13.0	13.3	13.6	14.0	14.4	14.7	15.0	40.1	12.9	13.3	13.7	14.1	14.4	14.9	15.3	15.6	15.9

CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	19 MILES—30.58 Km.										20 MILES—32.19 Km.									
		R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET
650 000		1.78	9.69	10.2	10.6	11.0	11.3	11.8	12.2	12.6	12.9	1.87	10.2	10.7	11.2	11.6	11.9	12.4	12.9	13.2	13.6
600 000		1.91	9.80	10.3	10.7	11.1	11.4	11.9	12.3	12.7	13.0	2.01	10.3	10.9	11.3	11.7	12.0	12.5	13.0	13.4	13.7
550 000		2.08	9.90	10.4	10.8	11.2	11.5	12.0	12.4	12.8	13.1	2.19	10.4	11.0	11.4	11.8	12.1	12.6	13.1	13.5	13.8
500 000		2.27	10.0	10.5	10.9	11.3	11.6	12.1	12.5	12.9	13.2	2.39	10.5	11.1	11.5	11.9	12.2	12.8	13.2	13.6	13.9
450 000		2.52	10.1	10.7	11.1	11.4	11.7	12.2	12.7	13.0	13.3	2.65	10.7	11.2	11.7	12.0	12.4	12.9	13.3	13.7	14.0
400 000		2.82	10.3	10.8	11.2	11.6	11.9	12.4	12.8	13.2	13.5	2.97	10.9	11.4	11.8	12.2	12.5	13.1	13.5	13.9	14.2
350 000		3.21	10.5	11.0	11.4	11.8	12.1	12.6	13.0	13.4	13.7	3.38	11.0	11.6	12.0	12.4	12.7	13.2	13.7	14.1	14.4
300 000		3.74	10.6	11.2	11.6	11.9	12.2	12.8	13.2	13.5	13.8	3.93	11.2	11.7	12.2	12.6	12.9	13.4	13.9	14.2	14.6
250 000		4.47	10.9	11.4	11.8	12.1	12.5	13.0	13.4	13.7	14.0	4.71	11.4	12.0	12.4	12.8	13.1	13.6	14.1	14.5	14.8
211 600	0000	5.27	11.2	11.7	12.1	12.5	12.8	13.3	13.7	14.1	14.4	5.55	11.8	12.3	12.7	13.1	13.4	14.0	14.4	14.8	15.1
167 806	000	6.64	11.4	12.0	12.4	12.7	13.0	13.6	14.0	14.3	14.6	6.99	12.0	12.6	13.0	13.4	13.7	14.3	14.7	15.1	15.4
133 077	00	8.37	11.7	12.2	12.6	13.0	13.3	13.8	14.2	14.6	14.9	8.81	12.3	12.9	13.3	13.7	14.0	14.5	15.0	15.4	15.7
105 535	0	10.5	12.0	12.5	12.9	13.3	13.6	14.1	14.5	14.9	15.2	11.1	12.6	13.1	13.6	14.0	14.3	14.8	15.3	15.6	16.0
83 693	1	13.3	12.2	12.8	13.2	13.5	13.8	14.4	14.8	15.1	15.4	14.0	12.9	13.4	13.9	14.2	14.6	15.1	15.5	15.9	16.2
66 371	2	16.8	12.5	13.0	13.4	13.8	14.1	14.6	15.0	15.4	15.7	17.6	13.2	13.7	14.1	14.5	14.8	15.4	15.8	16.2	16.5
52 635	3	21.1	12.8	13.3	13.7	14.1	14.4	14.9	15.3	15.7	16.0	22.2	13.4	14.0	14.4	14.8	15.1	15.7	16.1	16.5	16.8
41 741	4	26.6	13.0	13.6	14.0	14.3	14.6	15.2	15.6	15.9	16.2	28.0	13.7	14.3	14.7	15.1	15.4	16.0	16.4	16.8	17.1
33 102	5	33.6	13.3	13.8	14.2	14.6	14.9	15.4	15.8	16.2	16.5	35.4	14.0	14.6	15.0	15.4	15.7	16.2	16.7	17.0	17.4
26 251	6	42.4	13.6	14.1	14.5	14.9	15.2	15.7	16.1	16.5	16.8	44.6	14.3	14.8	15.3	15.6	16.0	16.5	17.0	17.3	17.7

CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	21 MILES—33.80 Km.										22 MILES—35.41 Km.									
		R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET
650 000		1.96	10.7	11.3	11.8	12.1	12.5	13.1	13.5	13.9	14.2	2.06	11.2	11.8	12.3	12.7	13.1	13.7	14.2	14.6	14.9
600 000		2.12	10.8	11.4	11.9	12.3	12.6	13.2	13.6	14.0	14.4	2.22	11.4	11.9	12.4	12.8	13.2	13.8	14.3	14.7	15.1
550 000		2.30	10.9	11.5	12.0	12.4	12.7	13.3	13.7	14.1	14.5	2.41	11.5	12.1	12.5	13.0	13.3	13.9	14.4	14.8	15.2
500 000		2.51	11.1	11.6	12.1	12.5	12.8	13.4	13.9	14.3	14.6	2.63	11.6	12.2	12.7	13.1	13.4	14.0	14.5	14.9	15.3
450 000		2.78	11.2	11.8	12.2	12.6	13.0	13.5	14.0	14.4	14.7	2.91	11.7	12.3	12.8	13.2	13.6	14.2	14.7	15.1	15.4
400 000		3.12	11.4	12.0	12.4	12.8	13.2	13.7	14.2	14.6	14.9	3.27	11.9	12.5	13.0	13.4	13.8	14.4	14.9	15.3	15.6
350 000		3.55	11.6	12.1	12.6	13.0	13.3	13.9	14.4	14.8	15.1	3.72	12.1	12.7	13.2	13.6	14.0	14.6	15.0	15.5	15.8
300 000		4.13	11.8	12.3	12.8	13.2	13.5	14.1	14.6	15.0	15.3	4.33	12.3	12.9	13.4	13.8	14.2	14.8	15.3	15.7	16.0
250 000		4.94	12.0	12.6	13.0	13.4	13.8	14.3	14.8	15.2	15.5	5.18	12.6	13.2	13.6	14.1	14.4	15.0	15.5	15.9	16.3
211 600	0000	5.83	12.3	12.9	13.4	13.8	14.1	14.7	15.1	15.5	15.9	6.11	12.9	13.5	14.0	14.4	14.8	15.4	15.9	16.3	16.6
167 806	000	7.34	12.6	13.2	13.7	14.1	14.4	15.0	15.4	15.8	16.2	7.69	13.2	13.8	14.3	14.7	15.1	15.7	16.2	16.6	16.9
133 077	00	9.25	12.9	13.5	14.0	14.4	14.7	15.3	15.7	16.1	16.5	9.69	13.6	14.1	14.6	15.0	15.4	16.0	16.5	16.9	17.3
105 535	0	11.7	13.2	13.8	14.3	14.7	15.0	15.6	16.0	16.4	16.8	12.2	13.9	14.5	14.9	15.4	15.7	16.3	16.8	17.2	17.6
83 693	1	14.7	13.5	14.1	14.6	15.0	15.3	15.9	16.3	16.7	17.1	15.4	14.2	14.8	15.3	15.7	16.0	16.6	17.1	17.5	17.9
66 371	2	18.5	13.8	14.4	14.9	15.2	15.6	16.2	16.6	17.0	17.4	19.4	14.5	15.1	15.6	16.0	16.3	16.9	17.4	17.8	18.2
52 635	3	23.4	14.1	14.7	15.2	15.5	15.9	16.5	16.9	17.3	17.7	24.5	14.8	15.4	15.9	16.3	16.6	17.2	17.7	18.1	18.5
41 741	4	29.4	14.4	15.0	15.4	15.8	16.2	16.7	17.2	17.6	17.9	30.8	15.1	15.7	16.2	16.6	16.9	17.5	18.0	18.4	18.8
33 102	5	37.1	14.7	15.3	15.7	16.1	16.5	17.0	17.5	17.9	18.2	38.9	15.4	16.0	16.5	16.9	17.3	17.9	18.3	18.8	19.1
26 251	6	46.8	15.0	15.6	16.0	16.4	16.8	17.3	17.8	18.2	18.5	49.0	15.7	16.3	16.8	17.2	17.6	18.2	18.7	19.1	19.4

CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	23 MILES—37.02 Km.										24 MILES—38.62 Km.									
		R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET	R ★	2 FEET	2.5 FEET	3 FEET	3.5 FEET	4 FEET	5 FEET	6 FEET	7 FEET	8 FEET
650 000		2.15	11.7	12.4	12.9	13.3	13.7	14.3	14.8	15.2	15.6	2.24	12.2	12.9	13.4	13.9	14.3	14.9	15.4	15.9	16.3
600 000		2.32	11.9	12.5	13.0	13.4	13.8	14.4	14.9	15.4	15.7	2.42	12.4	13.0	13.6	14.0	14.4	15.1	15.6	16.0	16.4
550 000		2.51	12.0	12.6	13.1	13.5	13.9	14.5	15.1	15.5	15.9	2.62	12.5	13.2	13.7	14.1	14.5	15.2	15.7	16.2	16.5
500 000		2.75	12.1	12.7	13.3	13.7	14.1	14.7	15.2	15.6	16.0	2.87	12.6	13.3	13.8	14.3	14.7	15.3	15.8	16.3	16.7
450 000		3.05	12.3	12.9	13.4	13.8	14.2	14.8	15.3	15.8	16.1	3.18	12.8	13.5	14.0	14.4	14.8	15.5	16.0	16.4	16.8
400 000		3.41	12.5	13.1	13.6	14.0	14.4	15.0	15.5	16.0	16.3	3.56	13.0	13.7	14.2	14.7	15.0	15.7	16.2	16.7	17.1
350 000		3.89	12.7	13.3	13.8	14.2	14.6	15.2	15.7	16.2	16.5	4.06	13.2	13.9	14.4	14.8	15.2	15.9	16.4	16.9	17.3
300 000		4.52	12.9	13.5	14.0	14.4	14.8	15.4	15.9	16.4	16.7	4.72	13.4	14.1	14.6	15.1	15.5	16.1	16.6	17.1	17.5
250 000		5.41	13.1	13.8	14.3	14.7	15.1	15.7	16.2	16.6	17.0	5.65	13.7	14.4	14.9	15.3	15.7	16.4	16.9	17.4	17.7
211 600	0000	6.39	13.5	14.1	14.7	15.1	15.5	16.1	16.6	17.0	17.4	6.66	14.1	14.8	15.3	15.7	16.1	16.8	17.3	17.8	18.1
167 806	000	8.04	13.8	14.5	15.0	15.4	15.8	16.4	16.9	17.3	17.7	8.39	14.4	15.1	15.6	16.1	16.5	17.1	17.6	18.1	18.5
133 077	00	10.1	14.2	14.8	15.3	15.7	16.1	16.7	17.2	17.7	18.0	10.6	14.8	15.4	16.0	16.4	16.8	17.5	18.0	18.4	18.8
105 535	0	12.8	14.5	15.1	15.6	16.1	16.4	17.0	17.6	18.0	18.4	13.3	15.1	15.8	16.3	16.8	17.1	17.8	18.3	18.8	19.2
83 693	1	16.1	14.8	15.4	15.9	16.4	16.7	17.4	17.9	18.3	18.7	16.8	15.5	16.1	16.6	17.1	17.5	18.1	18.7	19.1	19.5
66 371	2	20.3	15.1	15.8	16.3	16.7	17.1	17.7	18.2	18.6	19.0	21.2	15.8	16.4	17.0	17.4	17.8	18.5	19.0	19.4	19.8
52 635	3	25.6	15.5	16.1	16.6	17.0	17.4	18.0	18.5	19.0	19.3	26.7	16.1	16.8	17.3	17.8	18.2	18.8	19.3	19.8	20.2
41 741	4	32.3	15.8	16.4	16.9	17.3	17.7	18.3	18.9	19.3	19.7	33.7	16.5	17.1	17.7	18.1	18.5	19.1	19.7	20.1	20.5
33 102	5	40.7	16.1	16.7	17.2	17.7	18.0	18.7	19.2	19.6	20.0	42.4	16.8	17.5	18.0	18.4	18.8	19.5	20.0	20.5	20.8
26 251	6	51.3	16.4	17.1	17.6	18.0	18.4	19.0	19.5	19.9	20.3	53.5	17.1	17.8	18.3	18.8	19.2	19.8	20.3	20.8	21.2

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

★ These 60 cycle resistances are for hard drawn copper at 25° C. (77° F.)

TABLE XXX—TOTAL 60 CYCLE RESISTANCE AND 60 CYCLE REACTANCE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

Total 60 cycle resistance R and total 60 cycle reactance X in ohms for each conductor of a single-phase, two-phase or three-phase circuit. (See foot-notes.)

Columns: Size of conductor — Circular mils (aluminum); American wire gauge (B&S). Number of wires — Alum; Steel. Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%. Total resistance R. Total reactance X for spacings D given below.

Circular mils (aluminum)	American wire gauge (B&S)	Alum	Steel	Copper equivalent	17 MILES—27.36 KM. Total resistance R	X: 2 feet 0.61 M.	2.5 feet 0.76 M	3 feet 0.91 M	3.5 feet 1.07 M	4 feet 1.22 M.	5 feet 1.52 M.	6 feet 1.83 M	7 feet 2.13 M	8 feet 2.44 M	18 MILES—28.97 KM. Total resistance R	X: 2 feet 0.61 M.	2.5 feet 0.76 M	3 feet 0.91 M.	3.5 feet 1.07 M	4 feet 1.22 M	5 feet 1.52 M	6 feet 1.83 M.	7 feet 2.13 M	8 feet 2.44 M
1 033 500		54	7	650 000	1.57	7.63	8.10	8.47	8.79	9.06	9.52	9.90	10.2	10.5	1.66	8.08	8.57	8.97	9.30	9.60	10.1	10.5	10.8	11.1
954 000		54	7	600 000	1.69	7.71	8.18	8.56	8.88	9.15	9.61	9.99	10.3	10.6	1.79	8.17	8.66	9.06	9.40	9.69	10.2	10.6	10.9	11.2
874 500		54	7	550 000	1.85	7.80	8.26	8.63	8.95	9.23	9.69	10.1	10.4	10.7	1.96	8.26	8.75	9.14	9.48	9.77	10.3	10.7	11.0	11.3
795 000		54	7	500 000	2.03	7.90	8.36	8.74	9.05	9.33	9.79	10.2	10.5	10.8	2.15	8.36	8.85	9.25	9.58	9.87	10.4	10.8	11.1	11.4
715 500		54	7	450 000	2.25	8.01	8.47	8.85	9.16	9.43	9.90	10.3	10.6	10.9	2.39	8.48	8.96	9.37	9.70	9.99	10.5	10.9	11.2	11.5
636 000		54	7	400 000	2.54	8.13	8.59	8.97	9.28	9.56	10.0	10.4	10.7	11.0	2.69	8.60	9.09	9.49	9.83	10.1	10.6	11.0	11.3	11.6
556 500		30	7	350 000	2.85	8.17	8.63	9.01	9.33	9.60	10.1	10.4	10.8	11.0	3.02	8.65	9.14	9.54	9.87	10.2	10.7	11.1	11.4	11.7
477 000		30	7	300 000	3.33	8.34	8.80	9.18	9.49	9.77	10.2	10.6	10.9	11.2	3.52	8.83	9.32	9.72	10.1	10.3	10.8	11.2	11.6	11.9
397 500		30	7	250 000	3.99	8.54	9.01	9.38	9.70	9.97	10.4	10.8	11.1	11.4	4.23	9.05	9.54	9.93	10.3	10.6	11.1	11.5	11.8	12.1
336 400		30	7	0 000	4.72	8.72	9.18	9.56	9.88	10.2	10.6	11.0	11.3	11.6	5.00	9.24	9.72	10.1	10.5	10.8	11.2	11.6	12.0	12.3
266 800		26	7	000	5.95	9.05	9.51	9.89	10.2	10.5	10.9	11.3	11.6	11.9	6.30	9.58	10.1	10.5	10.8	11.1	11.6	12.0	12.3	12.6
211 600	0 000	6	1	00	7.89	10.7	11.1	11.5	11.8	12.1	12.6	12.9	13.3	13.5	8.36	11.3	11.8	12.2	12.5	12.8	13.3	13.7	14.0	14.3
167 806	000	6	1	0	9.85	10.8	11.3	11.7	12.0	12.3	12.7	13.1	13.4	13.7	10.4	11.5	12.0	12.4	12.7	13.0	13.5	13.9	14.2	14.5
133 077	00	6	1	1	12.2	11.0	11.5	11.9	12.2	12.5	12.9	13.3	13.6	13.9	12.9	11.7	12.2	12.6	12.9	13.2	13.7	14.1	14.4	14.7
105 535	0	6	1	2	15.2	11.2	11.7	12.0	12.4	12.6	13.1	13.5	13.8	14.1	16.1	11.9	12.4	12.8	13.1	13.4	13.9	14.3	14.6	14.9
83 693	1	6	1	3	19.0	11.4	11.9	12.2	12.6	12.8	13.3	13.7	14.0	14.3	20.2	12.1	12.6	13.0	13.3	13.6	14.1	14.5	14.8	15.1
66 371	2	6	1	4	24.0	11.6	12.0	12.4	12.7	13.0	13.5	13.8	14.2	14.4	25.4	12.3	12.7	13.1	13.5	13.8	14.3	14.7	15.0	15.3
52 635	3	6	1	5	30.2	11.8	12.2	12.6	12.9	13.2	13.6	14.0	14.3	14.6	32.0	12.5	12.9	13.3	13.7	14.0	14.5	14.9	15.2	15.5
41 741	4	6	1	6	38.0	11.9	12.4	12.8	13.1	13.4	13.8	14.2	14.5	14.8	40.3	12.6	13.1	13.5	13.9	14.2	14.6	15.0	15.4	15.7

Circular mils (aluminum)	American wire gauge (B&S)	Alum	Steel	Copper equivalent	19 MILES—30.58 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft	20 MILES—32.19 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft
1 033 500		54	7	650 000	1.75	8.53	9.05	9.47	9.82	10.1	10.6	11.1	11.4	11.7	1.85	8.98	9.52	9.97	10.3	10.7	11.2	11.7	12.0	12.4
954 000		54	7	600 000	1.89	8.62	9.14	9.56	9.92	10.2	10.7	11.2	11.5	11.8	1.99	9.08	9.62	10.1	10.4	10.8	11.3	11.8	12.1	12.5
874 500		54	7	550 000	2.07	8.72	9.23	9.65	10.0	10.3	10.8	11.3	11.6	11.9	2.18	9.18	9.72	10.2	10.5	10.9	11.4	11.9	12.2	12.5
795 000		54	7	500 000	2.27	8.83	9.34	9.76	10.1	10.4	10.9	11.4	11.7	12.0	2.39	9.29	9.83	10.3	10.7	11.0	11.5	12.0	12.3	12.7
715 500		54	7	450 000	2.52	8.95	9.46	9.89	10.2	10.5	11.1	11.5	11.8	12.1	2.65	9.42	9.96	10.4	10.8	11.1	11.6	12.1	12.5	12.8
636 000		54	7	400 000	2.84	9.08	9.60	10.0	10.4	10.7	11.2	11.6	12.0	12.3	2.99	9.56	10.1	10.6	10.9	11.2	11.8	12.2	12.6	12.9
556 500		30	7	350 000	3.19	9.13	9.65	10.1	10.4	10.7	11.3	11.7	12.0	12.3	3.35	9.61	10.2	10.6	11.0	11.3	11.8	12.3	12.7	13.0
477 000		30	7	300 000	3.72	9.32	9.83	10.3	10.6	10.9	11.4	11.9	12.2	12.5	3.91	9.81	10.4	10.8	11.2	11.5	12.0	12.5	12.9	13.2
397 500		30	7	250 000	4.46	9.55	10.1	10.5	10.8	11.2	11.7	12.1	12.4	12.7	4.70	10.1	10.6	11.0	11.4	11.7	12.3	12.7	13.1	13.4
336 400		30	7	0 000	5.27	9.75	10.3	10.7	11.0	11.4	11.9	12.3	12.6	12.9	5.55	10.3	10.8	11.3	11.6	11.9	12.5	12.9	13.3	13.6
266 800		26	7	000	6.65	10.1	10.6	11.1	11.4	11.7	12.2	12.7	13.0	13.3	7.00	10.7	11.2	11.6	12.0	12.3	12.9	13.3	13.7	14.0
211 600	0 000	6	1	00	8.82	11.9	12.4	12.9	13.2	13.5	14.0	14.5	14.8	15.1	9.28	12.6	13.1	13.5	13.9	14.2	14.8	15.2	15.6	15.9
167 806	000	6	1	0	11.0	12.1	12.6	13.1	13.4	13.7	14.2	14.7	15.0	15.3	11.6	12.8	13.3	13.8	14.1	14.4	15.0	15.4	15.8	16.1
133 077	00	6	1	1	13.7	12.3	12.8	13.3	13.6	13.9	14.4	14.9	15.2	15.5	14.4	13.0	13.5	14.0	14.3	14.7	15.2	15.6	16.0	16.3
105 535	0	6	1	2	17.0	12.5	13.0	13.5	13.8	14.1	14.6	15.1	15.4	15.7	17.9	13.2	13.7	14.2	14.5	14.9	15.4	15.9	16.2	16.5
83 693	1	6	1	3	21.3	12.7	13.3	13.7	14.0	14.3	14.9	15.3	15.6	15.9	22.4	13.4	14.0	14.4	14.8	15.1	15.6	16.1	16.4	16.8
66 371	2	6	1	4	26.8	12.9	13.5	13.9	14.2	14.5	15.1	15.5	15.8	16.1	28.2	13.6	14.2	14.6	15.0	15.3	15.8	16.3	16.7	17.0
52 635	3	6	1	5	33.7	13.1	13.7	14.1	14.4	14.7	15.3	15.7	16.0	16.3	35.5	13.8	14.4	14.8	15.2	15.5	16.1	16.5	16.9	17.2
41 741	4	6	1	6	42.5	13.4	13.9	14.3	14.6	14.9	15.5	15.9	16.2	16.5	44.7	14.1	14.6	15.0	15.4	15.7	16.3	16.7	17.1	17.4

Circular mils (aluminum)	American wire gauge (B&S)	Alum	Steel	Copper equivalent	21 MILES—33.80 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft	22 MILES—35.41 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft
1 033 500		54	7	650 000	1.94	9.43	10.0	10.5	10.9	11.2	11.8	12.2	12.6	13.0	2.03	9.88	10.5	11.0	11.4	11.7	12.3	12.8	13.2	13.6
954 000		54	7	600 000	2.09	9.53	10.1	10.6	11.0	11.3	11.9	12.3	12.7	13.1	2.19	9.99	10.6	11.1	11.5	11.8	12.4	12.9	13.3	13.7
874 500		54	7	550 000	2.29	9.64	10.2	10.7	11.1	11.4	12.0	12.4	12.8	13.2	2.40	10.1	10.7	11.2	11.6	11.9	12.5	13.0	13.4	13.8
795 000		54	7	500 000	2.51	9.76	10.3	10.8	11.2	11.5	12.1	12.6	12.9	13.3	2.63	10.2	10.8	11.3	11.7	12.1	12.7	13.2	13.6	13.9
715 500		54	7	450 000	2.79	9.89	10.5	10.9	11.3	11.7	12.2	12.7	13.1	13.4	2.92	10.4	11.0	11.5	11.9	12.2	12.8	13.3	13.7	14.1
636 000		54	7	400 000	3.14	10.0	10.6	11.1	11.5	11.8	12.4	12.8	13.2	13.6	3.29	10.5	11.1	11.6	12.0	12.4	13.0	13.5	13.9	14.2
556 500		30	7	350 000	3.52	10.1	10.7	11.1	11.5	11.9	12.4	12.9	13.3	13.6	3.69	10.6	11.2	11.7	12.1	12.4	13.0	13.5	13.9	14.3
477 000		30	7	300 000	4.11	10.3	10.9	11.3	11.7	12.1	12.6	13.1	13.5	13.8	4.31	10.8	11.4	11.9	12.3	12.6	13.2	13.7	14.1	14.5
397 500		30	7	250 000	4.93	10.6	11.1	11.6	12.0	12.3	12.9	13.4	13.7	14.1	5.17	11.1	11.7	12.1	12.6	12.9	13.5	14.0	14.4	14.8
336 400		30	7	0 000	5.83	10.8	11.3	11.8	12.2	12.5	13.1	13.6	14.0	14.3	6.11	11.3	11.9	12.4	12.8	13.1	13.7	14.2	14.6	15.0
266 800		26	7	000	7.35	11.2	11.8	12.2	12.6	12.9	13.5	14.0	14.4	14.7	7.70	11.7	12.3	12.8	13.2	13.6	14.2	14.7	15.1	15.4
211 600	0 000	6	1	00	9.75	13.2	13.8	14.2	14.6	15.0	15.5	16.0	16.4	16.7	10.2	13.8	14.4	14.9	15.3	15.7	16.3	16.8	17.2	17.5
167 806	000	6	1	0	12.2	13.4	14.0	14.4	14.8	15.2	15.7	16.2	16.6	16.9	12.8	14.0	14.6	15.1	15.5	15.9	16.5	17.0	17.4	17.7
133 077	00	6	1	1	15.1	13.6	14.2	14.7	15.0	15.4	16.0	16.4	16.8	17.2	15.8	14.3	14.9	15.4	15.8	16.1	16.7	17.2	17.6	18.0
105 535	0	6	1	2	18.8	13.8	14.4	14.9	15.3	15.6	16.2	16.6	17.0	17.4	19.7	14.5	15.1	15.6	16.0	16.4	16.9	17.4	17.8	18.2
83 693	1	6	1	3	23.5	14.1	14.7	15.1	15.5	15.8	16.4	16.9	17.3	17.6	24.6	14.8	15.4	15.8	16.2	16.6	17.2	17.7	18.1	18.4
66 371	2	6	1	4	29.6	14.3	14.9	15.3	15.7	16.1	16.6	17.1	17.5	17.8	31.0	15.0	15.6	16.1	16.5	16.8	17.4	17.9	18.3	18.7
52 635	3	6	1	5	37.3	14.5	15.1	15.6	16.0	16.3	16.9	17.3	17.7	18.1	39.1	15.2	15.8	16.3	16.7	17.1	17.7	18.2	18.6	18.9
41 741	4	6	1	6	47.0	14.8	15.3	15.8	16.2	16.5	17.1	17.6	17.9	18.3	49.2	15.5	16.1	16.5	16.9	17.3	17.9	18.4	18.8	19.2

Circular mils (aluminum)	American wire gauge (B&S)	Alum	Steel	Copper equivalent	23 MILES—37.02 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft	24 MILES—38.62 KM. R	2 ft	2.5 ft	3 ft	3.5 ft	4 ft	5 ft	6 ft	7 ft	8 ft
1 033 500		54	7	650 000	2.12	10.3	11.0	11.5	11.9	12.3	12.9	13.4	13.8	14.2	2.21	10.8	11.4	12.0	12.4	12.8	13.4	14.0	14.4	14.8
954 000		54	7	600 000	2.29	10.4	11.1	11.6	12.0	12.4	13.0	13.5	13.9	14.3	2.39	10.9	11.6	12.1	12.5	12.9	13.6	14.1	14.6	14.9
874 500		54	7	550 000	2.51	10.6	11.2	11.7	12.1	12.5	13.1	13.6	14.1	14.4	2.61	11.0	11.7	12.2	12.6	13.0	13.7	14.2	14.7	15.1
795 000		54	7	500 000	2.74	10.7	11.3	11.8	12.2	12.6	13.2	13.8	14.2	14.6	2.86	11.2	11.8	12.3	12.8	13.2	13.8	14.4	14.8	15.2
715 500		54	7	450 000	3.05	10.8	11.5	12.0	12.4	12.8	13.4	13.9	14.3	14.7	3.18	11.3	12.0	12.5	12.9	13.3	14.0	14.5	15.0	15.3
636 000		54	7	400 000	3.44	11.0	11.6	12.1	12.6	12.9	13.6	14.1	14.5	14.9	3.59	11.5	12.1	12.7	13.1	13.5	14.1	14.7	15.1	15.5
556 500		30	7	350 000	3.86	11.1	11.7	12.2	12.6	13.0	13.6	14.1	14.6	14.9	4.03	11.5	12.2	12.7	13.2	13.6	14.2	14.7	15.2	15.6
477 000		30	7	300 000	4.50	11.3	11.9	12.4	12.8	13.2	13.8	14.4	14.8	15.2	4.70	11.8	12.4	13.0	13.4	13.8	14.4	15.0	15.4	15.8
397 500		30	7	250 000	5.40	11.6	12.2	12.7	13.1	13.5	14.1	14.6	15.1	15.4	5.64	12.1	12.7	13.3	13.7	14.1	14.7	15.3	15.7	16.1
336 400		30	7	0 000	6.38	11.8	12.4	12.9	13.4	13.7	14.4	14.9	15.3	15.7	6.66	12.3	13.0	13.5	13.9	14.3	15.0	15.5	16.0	16.4
266 800		26	7	000	8.05	12.2	12.9	13.4	13.8	14.2	14.8	15.3	15.7	16.1	8.40	12.8	13.4	14.0	14.4	14.8	15.4	16.0	16.4	16.8
211 600	0 000	6	1	00	10.7	14.4	15.1	15.6	16.0	16.4	17.0	17.5	17.9	18.3	11.1	15.1	15.7	16.3	16.7	17.1	17.7	18.3	18.7	19.1
167 806	000	6	1	0	13.3	14.7	15.3	15.8	16.2	16.6	17.2	17.7	18.2	18.5	13.9	15.3	16.0	16.5	16.9	17.3	18.0	18.5	19.0	19.3
133 077	00	6	1	1	16.5	14.9	15.5	16.1	16.5	16.9	17.5	18.0	18.4	18.8	17.2	15.6	16.2	16.8	17.2	17.6	18.2	18.8	19.2	19.6
105 535	0	6	1	2	20.6	15.2	15.8	16.3	16.7	17.1	17.7	18.2	18.7	19.0	21.4	15.8	16.5	17.0	17.5	17.8	18.5	19.0	19.5	19.9
83 693	1	6	1	3	25.8	15.4	16.0	16.6	17.0	17.4	18.0	18.5	18.9	19.3	26.9	16.1	16.7	17.3	17.7	18.1	18.8	19.3	19.7	20.1
66 371	2	6	1	4	32.4	15.7	16.3	16.8	17.2	17.6	18.2	18.7	19.2	19.5	33.8	16.3	17.0	17.5	18.0	18.4	19.0	19.5	20.0	20.4
52 635	3	6	1	5	40.9	15.9	16.5	17.0	17.5	17.8	18.5	19.0	19.4	19.8	42.6	16.6	17.3	17.8	18.2	18.6	19.3	19.8	20.2	20.6
41 741	4	6	1	6	51.5	16.2	16.8	17.3	17.7	18.1	18.7	19.2	19.7	20.0	53.7	16.9	17.5	18.0	18.5	18.9	19.5	20.1	20.5	20.9

These 60 cycle resistances are based upon a temperature of 25° C. (77° F.) and a current density of 600 amperes per square inch as given in table VI. The reactances are based upon all current densities for the multiple layer conductors and upon 600 amperes per square inch for the single layer conductors as given in table XII.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.


Unsymmetrical triangular spacing


Symmetrical triangular spacing


Irregular flat spacing


Regular flat spacing

TABLE XXXI—TOTAL 60 CYCLE RESISTANCE AND TOTAL 60 CYCLE REACTANCE

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

SIZE OF CONDUCTOR		25 MILES—40.23 Km.										26 MILES—41.84 Km.									
CIRCULAR MILS	AMERICAN WIRE GAUGE B&S	TOTAL RESISTANCE R ★	TOTAL REACTANCE X									TOTAL RESISTANCE R ★	TOTAL REACTANCE X								
			2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)		2 FEET (0.61 M.)	2.5 FEET (0.76 M.)	3 FEET (0.91 M.)	3.5 FEET (1.07 M.)	4 FEET (1.22 M.)	5 FEET (1.52 M.)	6 FEET (1.83 M.)	7 FEET (2.13 M.)	8 FEET (2.44 M.)
650 000		2.34	12.8	13.4	14.0	14.5	14.9	15.5	16.1	16.6	17.0	2.43	13.3	14.0	14.5	15.0	15.4	16.2	16.7	17.2	17.6
600 000		2.52	12.9	13.6	14.1	14.6	15.0	15.7	16.2	16.7	17.1	2.62	13.4	14.1	14.7	15.2	15.6	16.3	16.9	17.4	17.8
550 000		2.73	13.0	13.7	14.3	14.7	15.1	15.8	16.4	16.8	17.2	2.84	13.6	14.3	14.8	15.3	15.7	16.4	17.0	17.5	17.9
500 000		2.99	13.2	13.9	14.4	14.9	15.3	16.0	16.5	17.0	17.4	3.11	13.7	14.4	15.0	15.5	15.9	16.6	17.2	17.7	18.1
450 000		3.31	13.3	14.0	14.6	15.0	15.4	16.1	16.7	17.1	17.5	3.44	13.9	14.6	15.1	15.6	16.0	16.8	17.3	17.8	18.2
400 000		3.71	13.6	14.2	14.8	15.3	15.7	16.3	16.9	17.4	17.8	3.86	14.1	14.8	15.4	15.9	16.3	17.0	17.6	18.1	18.5
350 000		4.23	13.8	14.4	15.0	15.5	15.9	16.5	17.1	17.6	18.0	4.39	14.3	15.0	15.6	16.1	16.5	17.2	17.8	18.3	18.7
300 000		4.92	14.0	14.7	15.2	15.7	16.1	16.8	17.3	17.8	18.2	5.11	14.6	15.3	15.8	16.3	16.7	17.5	18.0	18.5	18.9
250 000		5.89	14.3	15.0	15.5	16.0	16.4	17.1	17.6	18.1	18.5	6.12	14.8	15.6	16.1	16.6	17.0	17.7	18.3	18.8	19.2
211 600	0000	6.94	14.7	15.4	15.9	16.4	16.8	17.5	18.0	18.5	18.9	7.22	15.3	16.0	16.6	17.1	17.5	18.2	18.7	19.2	19.7
167 806	000	8.74	15.0	15.7	16.3	16.7	17.2	17.8	18.4	18.8	19.3	9.09	15.6	16.4	16.9	17.4	17.8	18.5	19.1	19.6	20.0
133 077	00	11.0	15.4	16.1	16.6	17.1	17.5	18.2	18.7	19.2	19.6	11.5	16.0	16.7	17.3	17.8	18.2	18.9	19.5	20.0	20.4
105 535	0	13.9	15.8	16.4	17.0	17.5	17.9	18.5	19.1	19.6	20.0	14.4	16.4	17.1	17.7	18.1	18.6	19.3	19.8	20.3	20.8
83 693	1	17.5	16.1	16.8	17.3	17.8	18.2	18.9	19.4	19.9	20.3	18.2	16.7	17.5	18.0	18.5	18.9	19.6	20.2	20.7	21.1
66 371	2	22.1	16.5	17.1	17.7	18.2	18.6	19.2	19.8	20.3	20.7	22.9	17.1	17.8	18.4	18.9	19.3	20.0	20.6	21.1	21.5
52 635	3	27.8	16.8	17.5	18.0	18.5	18.9	19.6	20.1	20.6	21.0	28.9	17.5	18.2	18.8	19.2	19.7	20.4	20.9	21.4	21.9
41 741	4	35.1	17.2	17.8	18.4	18.9	19.3	19.9	20.5	21.0	21.4	36.5	17.8	18.5	19.1	19.6	20.0	20.7	21.3	21.8	22.2
33 102	5	44.2	17.5	18.2	18.7	19.2	19.6	20.3	20.8	21.3	21.7	46.0	18.2	18.9	19.5	20.0	20.4	21.1	21.7	22.2	22.6
26 251	6	55.7	17.9	18.5	19.1	19.6	20.0	20.6	21.2	21.7	22.1	58.0	18.6	19.3	19.9	20.3	20.8	21.5	22.0	22.5	23.0

SIZE OF CONDUCTOR		27 MILES—43.45 Km.										28 MILES—45.06 Km.									
650 000		2.52	13.8	14.5	15.1	15.6	16.0	16.8	17.4	17.9	18.3	2.62	14.3	15.0	15.7	16.2	16.6	17.4	18.0	18.5	19.0
600 000		2.72	13.9	14.7	15.3	15.8	16.2	16.9	17.5	18.0	18.5	2.82	14.4	15.2	15.8	16.3	16.8	17.6	18.2	18.7	19.2
550 000		2.95	14.1	14.8	15.4	15.9	16.3	17.1	17.7	18.2	18.6	3.06	14.6	15.4	16.0	16.5	16.9	17.7	18.3	18.8	19.3
500 000		3.23	14.2	15.0	15.6	16.1	16.5	17.2	17.8	18.3	18.8	3.35	14.8	15.5	16.1	16.7	17.1	17.9	18.5	19.0	19.5
450 000		3.58	14.4	15.1	15.7	16.2	16.7	17.4	18.0	18.5	18.9	3.71	14.9	15.7	16.3	16.8	17.3	18.0	18.7	19.2	19.6
400 000		4.01	14.6	15.4	16.0	16.5	16.9	17.6	18.2	18.8	19.2	4.16	15.2	15.9	16.6	17.1	17.5	18.3	18.9	19.4	19.9
350 000		4.56	14.9	15.6	16.2	16.7	17.1	17.9	18.5	19.0	19.4	4.73	15.4	16.2	16.8	17.3	17.8	18.5	19.2	19.7	20.1
300 000		5.31	15.1	15.9	16.4	17.0	17.4	18.1	18.7	19.2	19.7	5.51	15.7	16.4	17.1	17.6	18.0	18.8	19.4	19.9	20.4
250 000		6.36	15.4	16.1	16.7	17.3	17.7	18.4	19.0	19.5	20.0	6.59	16.0	16.7	17.4	17.9	18.3	19.1	19.7	20.2	20.7
211 600	0000	7.50	15.9	16.6	17.2	17.7	18.1	18.9	19.5	20.0	20.4	7.77	16.5	17.2	17.8	18.4	18.8	19.6	20.2	20.7	21.2
167 806	000	9.44	16.3	17.0	17.6	18.1	18.5	19.3	19.9	20.4	20.8	9.79	16.9	17.6	18.2	18.8	19.2	20.0	20.6	21.1	21.6
133 077	00	11.9	16.6	17.4	18.0	18.5	18.9	19.6	20.2	20.7	21.2	12.3	17.2	18.0	18.6	19.1	19.6	20.4	21.0	21.5	22.0
105 535	0	15.0	17.0	17.7	18.3	18.8	19.3	20.0	20.6	21.1	21.6	15.5	17.6	18.4	19.0	19.5	20.0	20.8	21.4	21.9	22.4
83 693	1	18.9	17.4	18.1	18.7	19.2	19.7	20.4	21.0	21.5	21.9	19.6	18.0	18.8	19.4	19.9	20.4	21.1	21.8	22.3	22.7
66 371	2	23.8	17.8	18.5	19.1	19.6	20.0	20.8	21.4	21.9	22.3	24.7	18.4	19.2	19.8	20.3	20.8	21.5	22.2	22.7	23.1
52 635	3	30.0	18.2	18.9	19.5	20.0	20.4	21.2	21.8	22.3	22.7	31.1	18.8	19.6	20.2	20.7	21.2	21.9	22.6	23.1	23.5
41 741	4	37.9	18.5	19.3	19.9	20.4	20.8	21.5	22.1	22.6	23.1	39.3	19.2	20.0	20.6	21.1	21.6	22.3	22.9	23.5	23.9
33 102	5	47.7	18.9	19.6	20.2	20.7	21.2	21.9	22.5	23.0	23.5	49.5	19.6	20.4	21.0	21.5	22.0	22.7	23.3	23.9	24.3
26 251	6	60.2	19.3	20.0	20.6	21.1	21.6	22.3	22.9	23.4	23.8	62.4	20.0	20.8	21.4	21.9	22.4	23.1	23.7	24.3	24.7

SIZE OF CONDUCTOR		29 MILES—46.67 Km.										30 MILES—48.28 Km.									
650 000		2.71	14.8	15.6	16.2	16.8	17.2	18.0	18.7	19.2	19.7	2.80	15.3	16.1	16.8	17.3	17.8	18.6	19.3	19.9	20.4
600 000		2.92	15.0	15.7	16.4	16.9	17.4	18.2	18.8	19.4	19.8	3.02	15.5	16.3	17.0	17.5	18.0	18.8	19.5	20.0	20.5
550 000		3.17	15.1	15.9	16.5	17.1	17.6	18.3	19.0	19.5	20.0	3.28	15.6	16.4	17.1	17.7	18.2	19.0	19.6	20.2	20.7
500 000		3.47	15.3	16.1	16.7	17.3	17.7	18.5	19.1	19.7	20.2	3.59	15.8	16.6	17.3	17.8	18.3	19.1	19.8	20.4	20.9
450 000		3.84	15.5	16.3	16.9	17.4	17.9	18.7	19.3	19.9	20.3	3.97	16.0	16.8	17.5	18.0	18.5	19.3	20.0	20.6	21.0
400 000		4.30	15.7	16.5	17.2	17.7	18.2	19.0	19.6	20.1	20.6	4.45	16.3	17.1	17.8	18.3	18.8	19.6	20.3	20.8	21.3
350 000		4.90	16.0	16.8	17.4	17.9	18.4	19.2	19.8	20.4	20.8	5.07	16.5	17.3	18.0	18.6	19.0	19.9	20.5	21.1	21.6
300 000		5.70	16.2	17.0	17.7	18.2	18.7	19.5	20.1	20.6	21.1	5.90	16.8	17.6	18.3	18.8	19.3	20.1	20.8	21.4	21.8
250 000		6.83	16.6	17.3	18.0	18.5	19.0	19.8	20.4	21.0	21.4	7.06	17.1	17.9	18.6	19.2	19.7	20.5	21.1	21.7	22.2
211 600	0000	8.05	17.0	17.8	18.5	19.0	19.5	20.3	20.9	21.5	21.9	8.33	17.6	18.4	19.1	19.7	20.2	21.0	21.6	22.2	22.7
167 806	000	10.1	17.5	18.2	18.9	19.4	19.9	20.7	21.3	21.9	22.3	10.5	18.1	18.9	19.5	20.1	20.6	21.4	22.1	22.6	23.1
133 077	00	12.8	17.9	18.6	19.3	19.8	20.3	21.1	21.7	22.3	22.7	13.2	18.5	19.3	20.0	20.5	21.0	21.8	22.5	23.0	23.5
105 535	0	16.1	18.3	19.1	19.7	20.2	20.7	21.5	22.1	22.7	23.1	16.7	18.9	19.7	20.4	20.9	21.4	22.2	22.9	23.5	23.9
83 693	1	20.3	18.7	19.5	20.1	20.6	21.1	21.9	22.5	23.1	23.6	21.0	19.3	20.1	20.8	21.4	21.8	22.7	23.3	23.9	24.4
66 371	2	25.6	19.1	19.9	20.5	21.1	21.5	22.3	23.0	23.5	24.0	26.5	19.7	20.6	21.2	21.8	22.3	23.1	23.7	24.3	24.8
52 635	3	32.3	19.5	20.3	20.9	21.5	21.9	22.7	23.4	23.9	24.4	33.4	20.2	21.0	21.6	22.2	22.7	23.5	24.2	24.7	25.2
41 741	4	40.7	19.9	20.7	21.3	21.9	22.3	23.1	23.8	24.3	24.8	42.1	20.6	21.4	22.1	22.6	23.1	23.9	24.6	25.1	25.6
33 102	5	51.3	20.3	21.1	21.7	22.3	22.7	23.5	24.2	24.7	25.2	53.0	21.0	21.8	22.5	23.0	23.5	24.3	25.0	25.6	26.1
26 251	6	64.6	20.7	21.5	22.1	22.7	23.2	23.9	24.6	25.1	25.6	66.9	21.4	22.2	22.9	23.5	24.0	24.8	25.4	26.0	26.5

SIZE OF CONDUCTOR		32 MILES—51.50 Km.										34 MILES—54.72 Km.									
650 000		2.99	16.3	17.2	17.9	18.5	19.0	19.9	20.6	21.2	21.7	3.18	17.3	18.3	19.0	19.7	20.2	21.1	21.9	22.5	23.1
600 000		3.22	16.5	17.4	18.1	18.7	19.2	20.1	20.8	21.4	21.9	3.42	17.5	18.5	19.2	19.9	20.4	21.3	22.1	22.7	23.3
550 000		3.50	16.7	17.5	18.3	18.8	19.4	20.2	20.9	21.5	22.1	3.72	17.7	18.6	19.4	20.0	20.6	21.5	22.3	22.9	23.4
500 000		3.83	16.9	17.7	18.4	19.0	19.6	20.4	21.1	21.7	22.2	4.07	17.9	18.8	19.6	20.2	20.8	21.7	22.4	23.1	23.6
450 000		4.24	17.1	17.9	18.6	19.2	19.8	20.6	21.3	21.9	22.4	4.50	18.1	19.1	19.8	20.4	21.0	21.9	22.7	23.3	23.9
400 000		4.75	17.4	18.2	18.9	19.5	20.1	20.9	21.6	22.2	22.7	5.05	18.4	19.4	20.1	20.8	21.3	22.2	23.0	23.6	24.2
350 000		5.41	17.6	18.5	19.2	19.8	20.3	21.2	21.9	22.5	23.0	5.75	18.7	19.6	20.4	21.0	21.6	22.5	23.3	23.9	24.4
300 000		6.29	17.9	18.8	19.5	20.1	20.6	21.5	22.2	22.8	23.3	6.68	19.0	20.0	20.7	21.3	21.9	22.8	23.6	24.2	24.8
250 000		7.53	18.3	19.1	19.8	20.4	21.0	21.8	22.5	23.1	23.7	8.00	19.4	20.3	21.1	21.7	22.3	23.2	23.9	24.6	25.1
211 600	0000	8.88	18.8	19.7	20.4	21.0	21.5	22.4	23.1	23.7	24.2	9.44	20.0	20.9	21.7	22.3	22.8	23.8	24.5	25.2	25.7
167 806	000	11.2	19.3	20.1	20.8	21.4	22.0	22.8	23.5	24.1	24.6	11.9	20.5	21.4	22.1	22.8	23.3	24.2	25.0	25.6	26.2
133 077	00	14.1	19.7	20.6	21.3	21.9	22.4	23.3	24.0	24.6	25.1	15.0	20.9	21.9	22.6	23.3	23.8	24.7	25.5	26.1	26.7
105 535	0	17.8	20.2	21.0	21.7	22.3	22.9	23.7	24.4	25.0	25.5	18.9	21.4	22.3	23.1	23.7	24.3	25.2	26.0	26.6	27.1
83 693	1	22.4	20.6	21.5	22.2	22.8	23.3	24.2	24.9	25.5	26.0	23.8	21.9	22.8	23.6	24.2	24.8	25.7	26.4	27.1	27.6
66 371	2	28.2	21.1	21.9	22.6	23.2	23.8	24.6	25.3	25.9	26.4	30.0	22.4	23.3	24.0	24.7	25.2	26.2	26.9	27.5	28.1
52 635	3	35.6	21.5	22.4	23.1	23.7	24.2	25.1	25.8	26.4	26.9	37.8	22.9	23.8	24.5	25.2	25.7	26.6	27.4	28.0	28.6
41 741	4	44.9	22.0	22.8	23.5	24.1	24.7	25.5	26.2	26.8	27.3	47.7	23.3	24.3	25.0	25.6	26.2	27.1	27.9	28.5	29.1
33 102	5	56.6	22.4	23.3	24.0	24.6	25.1	26.0	26.7	27.3	27.8	60.1	23.8	24.7	25.5	26.1	26.7	27.6	28.3	29.0	29.5
26 251	6	71.3	22.9	23.7	24.4	25.0	25.6	26.4	27.1	27.7	28.2	75.8	24.3	25.2	26.0	26.6	27.2	28.1	28.8	29.5	30.0

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

★ These 60 cycle resistances are for hard drawn copper at 25° C. (77° F.)

TABLE XXXII—TOTAL 60 CYCLE RESISTANCE AND 60 CYCLE REACTANCE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE.

TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

Size of Conductor: Circular Mils (Aluminum)	Size of Conductor: American Wire Gauge B&S	Number of Wires: Alum	Number of Wires: Steel	Copper Equivalent Circular Mils or A. W. G. based upon Copper 97% Alumin. 61%	25 Miles—40.23 Km. Total Resistance R	X 2 feet 0.61 m.	X 2.5 feet 0.76 m.	X 3 feet 0.91 m.	X 3.5 feet 1.07 m.	X 4 feet 1.22 m.	X 5 feet 1.52 m.	X 6 feet 1.83 m.	X 7 feet 2.13 m.	X 8 feet 2.44 m.	26 Miles—41.84 Km. Total Resistance R	X 2 feet 0.61 m.	X 2.5 feet 0.76 m.	X 3 feet 0.91 m.	X 3.5 feet 1.07 m.	X 4 feet 1.22 m.	X 5 feet 1.52 m.	X 6 feet 1.83 m.	X 7 feet 2.13 m.	X 8 feet 2.44 m.
1 033 500		54	7	650 000	2.31	11.2	11.9	12.5	12.9	13.3	14.0	14.6	15.0	15.4	2.40	11.7	12.4	13.0	13.4	13.9	14.6	15.2	15.6	16.1
954 000		54	7	600 000	2.49	11.4	12.0	12.6	13.1	13.5	14.1	14.7	15.2	15.6	2.59	11.8	12.5	13.1	13.6	14.0	14.7	15.3	15.8	16.2
874 500		54	7	550 000	2.72	11.5	12.2	12.7	13.2	13.6	14.3	14.8	15.3	15.7	2.83	11.9	12.6	13.2	13.7	14.1	14.8	15.4	15.9	16.3
795 000		54	7	500 000	2.98	11.6	12.3	12.9	13.3	13.7	14.4	15.0	15.4	15.8	3.10	12.1	12.8	13.4	13.8	14.3	15.0	15.6	16.0	16.5
715 500		54	7	450 000	3.32	11.8	12.5	13.0	13.5	13.9	14.6	15.1	15.6	16.0	3.45	12.2	13.0	13.5	14.0	14.4	15.1	15.7	16.2	16.6
636 000		54	7	400 000	3.74	12.0	12.6	13.2	13.7	14.1	14.7	15.3	15.8	16.2	3.88	12.4	13.1	13.7	14.2	14.6	15.3	15.9	16.4	16.8
556 500		30	7	350 000	4.19	12.0	12.7	13.3	13.7	14.1	14.8	15.4	15.8	16.2	4.36	12.5	13.2	13.8	14.3	14.7	15.4	16.0	16.5	16.9
477 000		30	7	300 000	4.89	12.3	12.9	13.5	14.0	14.4	15.0	15.6	16.1	16.5	5.09	12.8	13.5	14.0	14.5	14.9	15.6	16.2	16.7	17.1
397 500		30	7	250 000	5.87	12.6	13.2	13.8	14.3	14.7	15.4	15.9	16.4	16.8	6.11	13.1	13.8	14.4	14.8	15.3	16.0	16.5	17.0	17.4
336 400		30	7	0 000	6.94	12.8	13.5	14.1	14.5	14.9	15.6	16.2	16.6	17.0	7.22	13.3	14.1	14.6	15.1	15.5	16.2	16.8	17.3	17.7
266 800		26	7	000	8.75	13.3	14.0	14.5	15.0	15.4	16.1	16.7	17.1	17.5	9.10	13.8	14.6	15.1	15.6	16.0	16.7	17.3	17.8	18.2
211 600	0 000	6	1	00	11.6	15.7	16.4	16.9	17.4	17.8	18.5	19.0	19.5	19.9	12.1	16.3	17.0	17.6	18.1	18.5	19.2	19.8	20.3	20.7
167 806	000	6	1	0	14.5	16.0	16.6	17.2	17.6	18.1	18.7	19.3	19.8	20.2	15.1	16.6	17.3	17.9	18.4	18.8	19.5	20.1	20.5	21.0
133 077	00	6	1	1	18.0	16.2	16.9	17.5	17.9	18.3	19.0	19.6	20.0	20.4	18.7	16.9	17.6	18.1	18.6	19.1	19.8	20.3	20.8	21.2
105 535	0	6	1	2	22.3	16.5	17.2	17.7	18.2	18.6	19.3	19.8	20.3	20.7	23.2	17.1	17.8	18.4	18.9	19.3	20.0	20.6	21.1	21.5
83 693	1	6	1	3	28.0	16.8	17.4	18.0	18.5	18.9	19.5	20.1	20.6	21.0	29.1	17.4	18.1	18.7	19.2	19.6	20.3	20.9	21.4	21.8
66 371	2	6	1	4	35.3	17.0	17.7	18.3	18.7	19.1	19.8	20.4	20.8	21.2	36.7	17.7	18.4	19.0	19.5	19.9	20.6	21.2	21.7	22.1
52 635	3	6	1	5	44.4	17.3	18.0	18.5	19.0	19.4	20.1	20.6	21.1	21.5	46.2	18.0	18.7	19.3	19.7	20.2	20.9	21.5	21.9	22.4
41 741	4	6	1	6	55.9	17.6	18.2	18.8	19.3	19.7	20.3	20.9	21.4	21.8	58.2	18.3	19.0	19.5	20.0	20.5	21.2	21.7	22.2	22.6

Circular Mils (Aluminum)	A. W. G. B&S	Alum	Steel	Copper Equivalent	27 Miles—43.45 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.	28 Miles—45.06 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.
1 033 500		54	7	650 000	2.49	12.1	12.9	13.5	14.0	14.4	15.1	15.7	16.2	16.7	2.58	12.6	13.3	14.0	14.5	14.9	15.7	16.3	16.8	17.3
954 000		54	7	600 000	2.69	12.3	13.0	13.6	14.1	14.5	15.3	15.9	16.4	16.8	2.79	12.7	13.5	14.1	14.6	15.1	15.8	16.5	17.0	17.4
874 500		54	7	550 000	2.94	12.4	13.1	13.7	14.2	14.7	15.4	16.0	16.5	16.9	3.05	12.9	13.6	14.2	14.8	15.2	16.0	16.6	17.1	17.6
795 000		54	7	500 000	3.22	12.5	13.3	13.9	14.4	14.8	15.5	16.1	16.6	17.1	3.34	13.0	13.8	14.4	14.9	15.4	16.1	16.7	17.3	17.7
715 500		54	7	450 000	3.58	12.7	13.5	14.1	14.5	15.0	15.7	16.3	16.8	17.3	3.71	13.2	13.9	14.6	15.1	15.5	16.3	16.9	17.4	17.9
636 000		54	7	400 000	4.03	12.9	13.6	14.2	14.7	15.2	15.9	16.5	17.0	17.5	4.18	13.4	14.2	14.8	15.3	15.7	16.5	17.1	17.6	18.1
556 500		30	7	350 000	4.53	13.0	13.7	14.3	14.8	15.3	16.0	16.6	17.1	17.5	4.70	13.5	14.2	14.8	15.4	15.8	16.6	17.2	17.7	18.2
477 000		30	7	300 000	5.28	13.2	14.0	14.6	15.1	15.5	16.3	16.9	17.3	17.8	5.48	13.7	14.5	15.1	15.6	16.1	16.9	17.5	18.0	18.4
397 500		30	7	250 000	6.34	13.6	14.3	14.9	15.4	15.8	16.6	17.2	17.7	18.1	6.57	14.1	14.8	15.5	16.0	16.4	17.2	17.8	18.3	18.8
336 400		30	7	0 000	7.49	13.9	14.6	15.2	15.7	16.1	16.9	17.5	18.0	18.4	7.77	14.4	15.1	15.8	16.3	16.7	17.5	18.1	18.6	19.1
266 800		26	7	000	9.45	14.4	15.1	15.7	16.2	16.6	17.4	18.0	18.5	18.9	9.80	14.9	15.7	16.3	16.8	17.3	18.0	18.6	19.2	19.6
211 600	0 000	6	1	00	12.5	17.0	17.7	18.3	18.8	19.2	20.0	20.6	21.1	21.5	13.0	17.6	18.3	19.0	19.5	19.9	20.7	21.3	21.8	22.3
167 806	000	6	1	0	15.6	17.2	18.0	18.6	19.1	19.5	20.2	20.8	21.3	21.8	16.2	17.9	18.6	19.2	19.8	20.2	21.0	21.6	22.1	22.6
133 077	00	6	1	1	19.4	17.5	18.2	18.8	19.3	19.8	20.5	21.1	21.6	22.1	20.1	18.2	18.9	19.5	20.1	20.5	21.3	21.9	22.4	22.9
105 535	0	6	1	2	24.1	17.8	18.5	19.1	19.6	20.1	20.8	21.4	21.9	22.3	25.0	18.5	19.2	19.8	20.4	20.8	21.6	22.2	22.7	23.2
83 693	1	6	1	3	30.2	18.1	18.8	19.4	19.9	20.4	21.1	21.7	22.2	22.6	31.4	18.8	19.5	20.2	20.7	21.1	21.9	22.5	23.0	23.5
66 371	2	6	1	4	38.1	18.4	19.1	19.7	20.2	20.7	21.4	22.0	22.5	22.9	39.5	19.1	19.8	20.5	21.0	21.4	22.2	22.8	23.3	23.8
52 635	3	6	1	5	48.0	18.7	19.4	20.0	20.5	20.9	21.7	22.3	22.8	23.2	49.7	19.4	20.1	20.7	21.3	21.7	22.5	23.1	23.6	24.1
41 741	4	6	1	6	60.4	19.0	19.7	20.3	20.8	21.2	22.0	22.6	23.1	23.5	62.6	19.7	20.4	21.1	21.6	22.0	22.8	23.4	23.9	24.4

Circular Mils (Aluminum)	A. W. G. B&S	Alum	Steel	Copper Equivalent	29 Miles—46.67 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.	30 Miles—48.28 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.
1 033 500		54	7	650 000	2.68	13.0	13.8	14.5	15.0	15.5	16.3	16.9	17.4	17.9	2.77	13.5	14.3	15.0	15.5	16.0	16.8	17.5	18.0	18.5
954 000		54	7	600 000	2.89	13.2	14.0	14.6	15.1	15.6	16.4	17.0	17.6	18.1	2.99	13.6	14.4	15.1	15.7	16.2	17.0	17.6	18.2	18.7
874 500		54	7	550 000	3.16	13.3	14.1	14.7	15.3	15.7	16.5	17.2	17.7	18.2	3.27	13.8	14.6	15.2	15.8	16.3	17.1	17.8	18.3	18.8
795 000		54	7	500 000	3.46	13.5	14.3	14.9	15.4	15.9	16.7	17.3	17.9	18.4	3.58	13.9	14.8	15.4	16.0	16.5	17.3	17.9	18.5	19.0
715 500		54	7	450 000	3.85	13.7	14.4	15.1	15.6	16.1	16.9	17.5	18.1	18.5	3.98	14.1	14.9	15.6	16.2	16.7	17.5	18.1	18.7	19.2
636 000		54	7	400 000	4.33	13.9	14.7	15.3	15.8	16.3	17.1	17.7	18.3	18.7	4.48	14.3	15.2	15.8	16.4	16.9	17.7	18.4	18.9	19.4
556 500		30	7	350 000	4.86	13.9	14.7	15.4	15.9	16.4	17.2	17.8	18.4	18.8	5.03	14.4	15.2	15.9	16.5	16.9	17.8	18.4	19.0	19.5
477 000		30	7	300 000	5.67	14.2	15.0	15.7	16.2	16.7	17.5	18.1	18.6	19.1	5.87	14.7	15.5	16.2	16.8	17.2	18.1	18.7	19.3	19.8
397 500		30	7	250 000	6.81	14.6	15.4	16.0	16.5	17.0	17.8	18.4	19.0	19.5	7.04	15.1	15.9	16.6	17.1	17.6	18.4	19.1	19.6	20.1
336 400		30	7	0 000	8.05	14.9	15.7	16.3	16.9	17.3	18.1	18.8	19.3	19.8	8.33	15.4	16.2	16.9	17.4	17.9	18.7	19.4	20.0	20.4
266 800		26	7	000	10.2	15.4	16.2	16.9	17.4	17.9	18.7	19.3	19.8	20.3	10.5	16.0	16.8	17.5	18.0	18.5	19.3	20.0	20.5	21.0
211 600	0 000	6	1	00	13.5	18.2	19.0	19.6	20.2	20.6	21.4	22.1	22.6	23.1	13.9	18.8	19.6	20.3	20.9	21.4	22.2	22.8	23.4	23.9
167 806	000	6	1	0	16.8	18.5	19.3	19.9	20.5	20.9	21.7	22.4	22.9	23.4	17.4	19.1	20.0	20.6	21.2	21.7	22.5	23.1	23.7	24.2
133 077	00	6	1	1	20.8	18.8	19.6	20.2	20.8	21.2	22.0	22.7	23.2	23.7	21.6	19.5	20.3	20.9	21.5	22.0	22.8	23.5	24.0	24.5
105 535	0	6	1	2	25.9	19.1	19.9	20.5	21.1	21.6	22.3	23.0	23.5	24.0	26.8	19.8	20.6	21.3	21.8	22.3	23.1	23.8	24.3	24.8
83 693	1	6	1	3	32.5	19.4	20.2	20.9	21.4	21.9	22.7	23.3	23.8	24.3	33.6	20.1	20.9	21.6	22.2	22.6	23.5	24.1	24.7	25.2
66 371	2	6	1	4	40.9	19.8	20.5	21.2	21.7	22.2	23.0	23.6	24.2	24.6	42.3	20.4	21.2	21.9	22.5	23.0	23.8	24.4	25.0	25.5
52 635	3	6	1	5	51.5	20.1	20.8	21.5	22.0	22.5	23.3	23.9	24.5	24.9	53.3	20.7	21.6	22.2	22.8	23.3	24.1	24.8	25.3	25.8
41 741	4	6	1	6	64.9	20.4	21.2	21.8	22.3	22.8	23.6	24.2	24.8	25.2	67.1	21.1	21.9	22.6	23.1	23.6	24.4	25.1	25.6	26.1

Circular Mils (Aluminum)	A. W. G. B&S	Alum	Steel	Copper Equivalent	32 Miles—51.50 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.	34 Miles—54.72 Km. R	X 2 ft.	X 2.5 ft.	X 3 ft.	X 3.5 ft.	X 4 ft.	X 5 ft.	X 6 ft.	X 7 ft.	X 8 ft.
1 033 500		54	7	650 000	2.95	14.4	15.2	16.0	16.5	17.1	17.9	18.6	19.2	19.8	3.14	15.3	16.2	17.0	17.6	18.1	19.1	19.8	20.4	21.0
954 000		54	7	600 000	3.19	14.5	15.4	16.1	16.7	17.2	18.1	18.8	19.4	19.9	3.39	15.4	16.4	17.1	17.8	18.3	19.2	20.0	20.6	21.2
874 500		54	7	550 000	3.49	14.7	15.6	16.3	16.9	17.4	18.2	19.0	19.5	20.1	3.70	15.6	16.5	17.3	17.9	18.5	19.4	20.1	20.8	21.3
795 000		54	7	500 000	3.82	14.9	15.7	16.4	17.0	17.6	18.4	19.1	19.7	20.2	4.06	15.8	16.7	17.5	18.1	18.7	19.6	20.3	21.0	21.5
715 500		54	7	450 000	4.24	15.1	15.9	16.7	17.2	17.8	18.6	19.3	19.9	20.5	4.51	16.0	16.9	17.7	18.3	18.9	19.8	20.6	21.2	21.7
636 000		54	7	400 000	4.78	15.3	16.2	16.9	17.5	18.0	18.9	19.6	20.2	20.7	5.08	16.3	17.2	17.9	18.6	19.1	20.0	20.8	21.4	22.0
556 500		30	7	350 000	5.37	15.4	16.3	17.0	17.6	18.1	18.9	19.7	20.2	20.8	5.70	16.3	17.3	18.0	18.7	19.2	20.1	20.9	21.5	22.1
477 000		30	7	300 000	6.26	15.7	16.6	17.3	17.9	18.4	19.3	20.0	20.6	21.1	6.65	16.7	17.6	18.4	19.0	19.5	20.5	21.2	21.8	22.4
397 500		30	7	250 000	7.51	16.1	17.0	17.7	18.3	18.8	19.6	20.4	20.9	21.5	7.98	17.1	18.0	18.8	19.4	19.9	20.9	21.6	22.3	22.8
336 400		30	7	0 000	8.88	16.4	17.3	18.0	18.6	19.1	20.0	20.7	21.3	21.8	9.44	17.5	18.4	19.1	19.8	20.3	21.2	22.0	22.6	23.2
266 800		26	7	000	11.2	17.0	17.9	18.6	19.2	19.7	20.6	21.3	21.9	22.4	11.9	18.1	19.0	19.8	20.4	21.0	21.9	22.6	23.3	23.8
211 600	0 000	6	1	00	14.9	20.1	21.0	21.7	22.3	22.8	23.6	24.4	25.0	25.5	15.8	21.3	22.3	23.0	23.7	24.2	25.1	25.9	26.5	27.1
167 806	000	6	1	0	18.5	20.4	21.3	22.0	22.6	23.1	24.0	24.7	25.3	25.8	19.7	21.7	22.6	23.4	24.0	24.6	25.5	26.2	26.9	27.4
133 077	00	6	1	1	23.0	20.8	21.6	22.3	22.9	23.4	24.3	25.0	25.6	26.1	24.4	22.1	23.0	23.7	24.4	24.9	25.8	26.6	27.2	27.8
105 535	0	6	1	2	28.6	21.1	22.0	22.7	23.3	23.8	24.7	25.4	26.0	26.5	30.4	22.4	23.3	24.1	24.7	25.3	26.2	27.0	27.6	28.1
83 693	1	6	1	3	35.8	21.5	22.3	23.0	23.6	24.1	25.0	25.7	26.3	26.8	38.1	22.8	23.7	24.5	25.1	25.7	26.6	27.3	28.0	28.5
66 371	2	6	1	4	45.1	21.8	22.7	23.4	24.0	24.5	25.4	26.1	26.7	27.2	47.9	23.2	24.1	24.8	25.5	26.0	26.9	27.7	28.3	28.9
52 635	3	6	1	5	56.8	22.1	23.0	23.7	24.3	24.8	25.7	26.4	27.0	27.5	60.4	23.5	24.4	25.2	25.8	26.4	27.3	28.1	28.7	29.2
41 741	4	6	1	6	71.6	22.5	23.3	24.1	24.7	25.2	26.0	26.8	27.3	27.9	76.1	23.9	24.8	25.6	26.2	26.7	27.7	28.4	29.1	29.6

· These 60 cycle resistances are based upon a temperature of 25° C. (77° F.) and a current density of 600 amperes per square inch as given in table VI. The reactances are based upon all current densities for the multiple layer conductors and upon 600 amperes per square inch for the single layer conductors as given in table XII.

For any three-phase arrangement of conductors $D \doteq \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XXXIII—TOTAL 60 CYCLE RESISTANCE AND TOTAL 60 CYCLE REACTANCE

COPPER CONDUCTORS—CONCENTRIC STRANDING

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

SIZE OF CONDUCTOR — TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT. (SEE FOOT-NOTES.)

36 MILES—57.94 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		3.36	18.4	19.3	20.1	20.8	21.4	22.4	23.2	23.8	24.4
600 000		3.63	18.6	19.5	20.3	21.0	21.6	22.6	23.4	24.0	24.6
550 000		3.94	18.8	19.7	20.5	21.2	21.8	22.8	23.6	24.2	24.8
500 000		4.31	19.0	19.9	20.7	21.4	22.0	23.0	23.8	24.4	25.0
450 000		4.77	19.2	20.2	21.0	21.6	22.2	23.2	24.0	24.7	25.3
400 000		5.34	19.5	20.5	21.3	22.0	22.6	23.5	24.3	25.0	25.6
350 000		6.08	19.8	20.8	21.6	22.3	22.9	23.8	24.6	25.3	25.9
300 000		7.08	20.2	21.1	21.9	22.6	23.2	24.2	25.0	25.6	26.2
250 000		8.47	20.6	21.5	22.3	23.0	23.6	24.6	25.4	26.0	26.6
211 600	0000	9.99	21.2	22.1	22.9	23.6	24.2	25.2	26.0	26.6	27.2
167 806	000	12.6	21.7	22.6	23.4	24.1	24.7	25.7	26.5	27.1	27.7
133 077	00	15.9	22.2	23.1	23.9	24.6	25.2	26.2	27.0	27.6	28.2
105 535	0	20.0	22.7	23.7	24.4	25.1	25.7	26.7	27.5	28.2	28.7
83 693	1	25.2	23.2	24.2	25.0	25.6	26.2	27.2	28.0	28.7	29.2
66 371	2	31.8	23.7	24.7	25.5	26.1	26.7	27.7	28.5	29.2	29.7
52 635	3	40.0	24.2	25.2	26.0	26.6	27.2	28.2	29.0	29.7	30.3
41 741	4	50.5	24.7	25.7	26.5	27.1	27.7	28.7	29.5	30.2	30.8
33 102	5	63.7	25.2	26.2	27.0	27.7	28.2	29.2	30.0	30.7	31.3
26 251	6	80.2	25.7	26.7	27.5	28.2	28.7	29.7	30.5	31.2	31.8

38 MILES—61.16 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		3.55	19.4	20.4	21.3	22.0	22.6	23.6	24.5	25.2	25.8
600 000		3.83	19.6	20.6	21.5	22.2	22.8	23.8	24.7	25.4	26.0
550 000		4.15	19.8	20.8	21.7	22.4	23.0	24.0	24.9	25.6	26.2
500 000		4.55	20.0	21.1	21.9	22.6	23.2	24.2	25.1	25.8	26.4
450 000		5.03	20.3	21.3	22.1	22.8	23.5	24.5	25.3	26.0	26.7
400 000		5.64	20.6	21.6	22.5	23.2	23.8	24.8	25.7	26.4	27.0
350 000		6.42	20.9	22.0	22.8	23.5	24.1	25.1	26.0	26.7	27.3
300 000		7.47	21.3	22.3	23.1	23.9	24.5	25.5	26.3	27.1	27.7
250 000		8.95	21.7	22.7	23.6	24.3	24.9	25.9	26.8	27.5	28.1
211 600	0000	10.6	22.3	23.4	24.2	24.9	25.5	26.6	27.4	28.1	28.7
167 806	000	13.3	22.9	23.9	24.7	25.4	26.1	27.1	27.9	28.6	29.3
133 077	00	16.7	23.4	24.4	25.3	26.0	26.6	27.6	28.5	29.2	29.8
105 535	0	21.1	23.9	25.0	25.8	26.5	27.1	28.2	29.0	29.7	30.3
83 693	1	26.6	24.5	25.5	26.3	27.1	27.7	28.7	29.5	30.2	30.9
66 371	2	33.5	25.0	26.0	26.9	27.6	28.2	29.2	30.1	30.8	31.4
52 635	3	42.3	25.5	26.6	27.4	28.1	28.7	29.8	30.6	31.3	31.9
41 741	4	53.3	26.1	27.1	27.9	28.7	29.3	30.3	31.1	31.9	32.5
33 102	5	67.2	26.6	27.6	28.5	29.2	29.8	30.8	31.7	32.4	33.0
26 251	6	84.7	27.1	28.2	29.0	29.7	30.3	31.4	32.2	32.9	33.5

40 MILES—64.37 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		3.74	20.4	21.5	22.4	23.1	23.8	24.9	25.7	26.5	27.1
600 000		4.03	20.6	21.7	22.6	23.4	24.0	25.1	26.0	26.7	27.4
550 000		4.37	20.8	21.9	22.8	23.6	24.2	25.3	26.2	26.9	27.6
500 000		4.79	21.1	22.2	23.0	23.8	24.4	25.5	26.4	27.2	27.8
450 000		5.30	21.3	22.4	23.3	24.0	24.7	25.8	26.7	27.4	28.1
400 000		5.94	21.7	22.8	23.7	24.4	25.1	26.1	27.0	27.8	28.4
350 000		6.76	22.0	23.1	24.0	24.7	25.4	26.5	27.4	28.1	28.8
300 000		7.86	22.4	23.5	24.4	25.1	25.8	26.8	27.7	28.5	29.1
250 000		9.42	22.8	23.9	24.8	25.6	26.2	27.3	28.2	28.9	29.6
211 600	0000	11.1	23.5	24.6	25.5	26.2	26.9	28.0	28.8	29.6	30.2
167 806	000	14.0	24.1	25.2	26.0	26.8	27.4	28.5	29.4	30.2	30.8
133 077	00	17.6	24.6	25.7	26.6	27.4	28.0	29.1	30.0	30.7	31.4
105 535	0	22.2	25.2	26.3	27.2	27.9	28.6	29.6	30.5	31.3	31.9
83 693	1	28.0	25.8	26.8	27.7	28.5	29.1	30.2	31.1	31.8	32.5
66 371	2	35.3	26.3	27.4	28.3	29.0	29.7	30.8	31.7	32.4	33.1
52 635	3	44.5	26.9	28.0	28.9	29.6	30.3	31.3	32.2	33.0	33.6
41 741	4	56.1	27.4	28.5	29.4	30.2	30.8	31.9	32.8	33.5	34.2
33 102	5	70.7	28.0	29.1	30.0	30.7	31.4	32.5	33.3	34.1	34.7
26 251	6	89.2	28.6	29.7	30.5	31.3	31.9	33.0	33.9	34.7	35.3

42 MILES—67.59 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		3.92	21.4	22.6	23.5	24.3	25.0	26.1	27.0	27.8	28.5
600 000		4.23	21.7	22.8	23.7	24.5	25.2	26.3	27.3	28.1	28.7
550 000		4.59	21.9	23.0	24.0	24.7	25.4	26.6	27.5	28.3	29.0
500 000		5.03	22.1	23.3	24.2	25.0	25.7	26.8	27.7	28.5	29.2
450 000		5.56	22.4	23.5	24.5	25.3	25.9	27.1	28.0	28.8	29.5
400 000		6.23	22.8	23.9	24.9	25.6	26.3	27.5	28.4	29.2	29.9
350 000		7.10	23.1	24.3	25.2	26.0	26.7	27.8	28.7	29.5	30.2
300 000		8.26	23.5	24.7	25.6	26.4	27.0	28.2	29.1	29.9	30.6
250 000		9.89	24.0	25.1	26.0	26.8	27.5	28.6	29.6	30.4	31.0
211 600	0000	11.7	24.7	25.8	26.8	27.5	28.2	29.4	30.3	31.1	31.8
167 806	000	14.7	25.3	26.4	27.3	28.1	28.8	29.9	30.9	31.7	32.3
133 077	00	18.5	25.9	27.0	27.9	28.7	29.4	30.5	31.5	32.3	32.9
105 535	0	23.3	26.5	27.6	28.5	29.3	30.0	31.1	32.1	32.8	33.5
83 693	1	29.4	27.0	28.2	29.1	29.9	30.6	31.7	32.6	33.4	34.1
66 371	2	37.0	27.6	28.8	29.7	30.5	31.2	32.3	33.2	34.0	34.7
52 635	3	46.7	28.2	29.4	30.3	31.1	31.8	32.9	33.8	34.6	35.3
41 741	4	58.9	28.8	30.0	30.9	31.7	32.4	33.5	34.4	35.2	35.9
33 102	5	74.3	29.4	30.6	31.5	32.3	32.9	34.1	35.0	35.8	36.5
26 251	6	93.6	30.0	31.1	32.1	32.9	33.5	34.7	35.6	36.4	37.1

44 MILES—70.81 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		4.11	22.4	23.6	24.6	25.4	26.1	27.3	28.3	29.1	29.9
600 000		4.43	22.7	23.9	24.9	25.7	26.4	27.6	28.6	29.4	30.1
550 000		4.81	22.9	24.1	25.1	25.9	26.6	27.8	28.8	29.6	30.3
500 000		5.27	23.2	24.4	25.3	26.2	26.9	28.1	29.0	29.9	30.6
450 000		5.83	23.5	24.7	25.6	26.5	27.2	28.4	29.3	30.2	30.9
400 000		6.53	23.9	25.1	26.0	26.9	27.6	28.8	29.7	30.6	31.3
350 000		7.44	24.2	25.4	26.4	27.2	27.9	29.1	30.1	30.9	31.6
300 000		8.65	24.6	25.8	26.8	27.6	28.3	29.5	30.5	31.3	32.0
250 000		10.4	25.1	26.3	27.3	28.1	28.8	30.0	31.0	31.8	32.5
211 600	0000	12.2	25.9	27.1	28.0	28.9	29.6	30.8	31.7	32.6	33.3
167 806	000	15.4	26.5	27.7	28.6	29.5	30.2	31.4	32.3	33.2	33.9
133 077	00	19.4	27.1	28.3	29.3	30.1	30.8	32.0	33.0	33.8	34.5
105 535	0	24.4	27.7	28.9	29.9	30.7	31.4	32.6	33.6	34.4	35.1
83 693	1	30.8	28.3	29.5	30.5	31.3	32.0	33.2	34.2	35.0	35.7
66 371	2	38.8	29.0	30.1	31.1	31.9	32.7	33.8	34.8	35.6	36.4
52 635	3	48.9	29.6	30.8	31.7	32.6	33.3	34.5	35.4	36.3	37.0
41 741	4	61.7	30.2	31.4	32.4	33.2	33.9	35.1	36.1	36.9	37.6
33 102	5	77.8	30.8	32.0	33.0	33.8	34.5	35.7	36.7	37.5	38.2
26 251	6	98.1	31.4	32.6	33.6	34.4	35.1	36.3	37.3	38.1	38.8

46 MILES—74.03 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		4.30	23.5	24.7	25.7	26.6	27.3	28.6	29.6	30.5	31.2
600 000		4.63	23.7	25.0	26.0	26.9	27.6	28.8	29.9	30.7	31.5
550 000		5.03	24.0	25.2	26.2	27.1	27.8	29.1	30.1	31.0	31.7
500 000		5.51	24.2	25.5	26.5	27.4	28.1	29.4	30.4	31.2	32.0
450 000		6.09	24.5	25.8	26.8	27.7	28.4	29.6	30.7	31.5	32.3
400 000		6.83	25.0	26.2	27.2	28.1	28.8	30.1	31.1	31.9	32.7
350 000		7.77	25.3	26.6	27.6	28.5	29.2	30.4	31.5	32.3	33.1
300 000		9.04	25.8	27.0	28.0	28.9	29.6	30.9	31.9	32.7	33.5
250 000		10.8	26.3	27.5	28.5	29.4	30.1	31.4	32.4	33.3	34.0
211 600	0000	12.8	27.0	28.3	29.3	30.2	30.9	32.1	33.2	34.0	34.8
167 806	000	16.1	27.7	28.9	29.9	30.8	31.6	32.8	33.8	34.7	35.4
133 077	00	20.3	28.3	29.6	30.6	31.5	32.2	33.4	34.5	35.3	36.1
105 535	0	25.5	29.0	30.2	31.2	32.1	32.8	34.1	35.1	36.0	36.7
83 693	1	32.2	29.6	30.9	31.9	32.7	33.5	34.7	35.8	36.6	37.4
66 371	2	40.6	30.3	31.5	32.5	33.4	34.1	35.4	36.4	37.3	38.0
52 635	3	51.2	30.9	32.2	33.2	34.0	34.8	36.0	37.1	37.9	38.7
41 741	4	64.5	31.6	32.8	33.8	34.7	35.4	36.7	37.7	38.6	39.3
33 102	5	81.3	32.2	33.5	34.5	35.3	36.1	37.3	38.3	39.2	40.0
26 251	6	103.	32.9	34.1	35.1	36.0	36.7	38.0	39.0	39.9	40.6

48 MILES—77.25 Km.

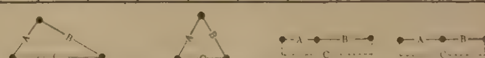
Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		4.49	24.5	25.8	26.9	27.7	28.5	29.8	30.9	31.8	32.6
600 000		4.83	24.8	26.1	27.1	28.0	28.8	30.1	31.2	32.1	32.8
550 000		5.25	25.0	26.3	27.4	28.3	29.0	30.4	31.4	32.3	33.1
500 000		5.75	25.3	26.6	27.7	28.6	29.3	30.6	31.7	32.6	33.4
450 000		6.36	25.6	26.9	28.0	28.9	29.6	30.9	32.0	32.9	33.7
400 000		7.12	26.0	27.3	28.4	29.3	30.1	31.4	32.4	33.3	34.1
350 000		8.11	26.4	27.7	28.8	29.7	30.5	31.8	32.8	33.7	34.5
300 000		9.44	26.9	28.2	29.2	30.1	30.9	32.2	33.3	34.2	34.9
250 000		11.3	27.4	28.7	29.8	30.7	31.4	32.7	33.8	34.7	35.5
211 600	0000	13.3	28.2	29.5	30.6	31.5	32.3	33.5	34.6	35.5	36.3
167 806	000	16.8	28.9	30.2	31.2	32.1	32.9	34.2	35.3	36.2	37.0
133 077	00	21.1	29.6	30.9	31.9	32.8	33.6	34.9	36.0	36.9	37.6
105 535	0	26.6	30.2	31.5	32.6	33.5	34.3	35.6	36.6	37.5	38.3
83 693	1	33.6	30.9	32.2	33.3	34.2	34.9	36.2	37.3	38.2	39.0
66 371	2	42.3	31.6	32.9	34.0	34.8	35.6	36.9	38.0	38.9	39.7
52 635	3	53.4	32.3	33.6	34.6	35.5	36.3	37.6	38.7	39.6	40.3
41 741	4	67.3	32.9	34.2	35.3	36.2	37.0	38.3	39.3	40.2	41.0
33 102	5	84.9	33.6	34.9	36.0	36.9	37.7	39.0	40.0	40.9	41.7
26 251	6	107.	34.3	35.6	36.7	37.6	38.3	39.6	40.7	41.6	42.4

50 MILES—80.47 Km.

Circular Mils	American Wire Gauge B&S	Total Resistance R ★	X 2 Feet 0.61 M	X 2.5 Feet 0.76 M	X 3 Feet 0.91 M	X 3.5 Feet 1.07 M	X 4 Feet 1.22 M	X 5 Feet 1.52 M	X 6 Feet 1.83 M	X 7 Feet 2.13 M	X 8 Feet 2.44 M
650 000		4.67	25.5	26.9	28.0	28.9	29.7	31.1	32.2	33.1	33.9
600 000		5.04	25.8	27.1	28.3	29.2	30.0	31.4	32.5	33.4	34.2
550 000		5.47	26.1	27.4	28.5	29.5	30.3	31.6	32.7	33.7	34.5
500 000		5.99	26.3	27.7	28.8	29.7	30.6	31.9	33.0	33.9	34.8
450 000		6.62	26.7	28.0	29.1	30.1	30.9	32.2	33.3	34.3	35.1
400 000		7.42	27.1	28.5	29.6	30.5	31.3	32.7	33.8	34.7	35.5
350 000		8.45	27.5	28.9	30.0	30.9	31.7	33.1	34.2	35.1	35.9
300 000		9.83	28.0	29.4	30.5	31.4	32.2	33.6	34.7	35.6	36.4
250 000		11.8	28.6	29.9	31.0	31.9	32.8	34.1	35.2	36.2	37.0
211 600	0000	13.9	29.4	30.7	31.8	32.8	33.6	34.9	36.1	37.0	37.8
167 806	000	17.5	30.1	31.4	32.6	33.5	34.3	35.7	36.8	37.7	38.5
133 077	00	22.0	30.8	32.2	33.3	34.2	35.0	36.4	37.5	38.4	39.2
105 535	0	27.8	31.5	32.9	34.0	34.9	35.7	37.1	38.2	39.1	39.9
83 693	1	35.0	32.2	33.6	34.7	35.6	36.4	37.8	38.9	39.8	40.6
66 371	2	44.1	32.9	34.3	35.4	36.3	37.1	38.5	39.6	40.5	41.3
52 635	3	55.6	33.6	35.0	36.1	37.0	37.8	39.2	40.3	41.2	42.0
41 741	4	70.1	34.3	35.7	36.8	37.7	38.5	39.9	41.0	41.9	42.7
33 102	5	88.4	35.0	36.4	37.5	38.4	39.2	40.6	41.7	42.6	43.4
26 251	6	112.	35.7	37.1	38.2	39.1	39.9	41.3	42.4	43.3	44.1

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

★ These 60 cycle resistances are for hard drawn copper at 25° C. (77° F.)



Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XXXIV—TOTAL 60 CYCLE RESISTANCE AND 60 CYCLE REACTANCE

ALUMINUM CABLE STEEL REINFORCED

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

TOTAL 60 CYCLE RESISTANCE R AND TOTAL 60 CYCLE REACTANCE X IN OHMS FOR EACH CONDUCTOR OF A SINGLE-PHASE, TWO-PHASE OR THREE-PHASE CIRCUIT (SEE FOOT-NOTES.)

Columns: SIZE OF CONDUCTOR — CIRCULAR MILS (ALUMINUM), AMERICAN WIRE GAUGE (B&S); NUMBER OF WIRES — ALUM, STEEL; COPPER EQUIVALENT CIRCULAR MILS OR A W G BASED UPON COPPER 97% ALUMIN. 61%; TOTAL RESISTANCE R; TOTAL REACTANCE X FOR SPACINGS D GIVEN BELOW.

36 MILES—57.94 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	3.32	16.2	17.1	17.9	18.6	19.2	20.2	21.0	21.7	22.2
954 000		54	7	600 000	3.59	16.3	17.3	18.1	18.8	19.4	20.3	21.2	21.8	22.4
874 500		54	7	550 000	3.92	16.5	17.5	18.3	19.0	19.5	20.5	21.3	22.0	22.6
795 000		54	7	500 000	4.30	16.7	17.7	18.5	19.2	19.8	20.7	21.5	22.2	22.8
715 500		54	7	450 000	4.77	17.0	17.9	18.7	19.4	20.0	21.0	21.8	22.4	23.0
636 000		54	7	400 000	5.38	17.2	18.2	19.0	19.7	20.2	21.2	22.0	22.7	23.3
556 500		30	7	350 000	6.04	17.3	18.3	19.1	19.8	20.3	21.3	22.1	22.8	23.4
477 000		30	7	300 000	7.05	17.7	18.6	19.4	20.1	20.7	21.7	22.5	23.1	23.7
397 500		30	7	250 000	8.45	18.1	19.1	19.9	20.5	21.1	22.1	22.9	23.6	24.2
336 400		30	7	0 000	9.99	18.5	19.5	20.3	20.9	21.5	22.5	23.3	23.9	24.5
266 800		26	7	000	12.6	19.2	20.1	20.9	21.6	22.2	23.2	24.0	24.6	25.2
211 600	0 000	6	1	00	16.7	22.6	23.6	24.4	25.0	25.6	26.6	27.4	28.1	28.7
167 806	000	6	1	0	20.9	23.0	23.9	24.7	25.4	26.0	27.0	27.8	28.4	29.0
133 077	00	6	1	1	25.9	23.3	24.3	25.1	25.8	26.4	27.4	28.2	28.8	29.4
105 535	0	6	1	2	32.2	23.7	24.7	25.5	26.2	26.8	27.7	28.5	29.2	29.8
83 693	1	6	1	3	40.3	24.1	25.1	25.9	26.6	27.2	28.1	28.9	29.6	30.2
66 371	2	6	1	4	50.8	24.5	25.5	26.3	27.0	27.5	28.5	29.3	30.0	30.6
52 635	3	6	1	5	63.9	24.9	25.9	26.7	27.3	27.9	28.9	29.7	30.4	31.0
41 741	4	6	1	6	80.5	25.3	26.3	27.1	27.7	28.3	29.3	30.1	30.8	31.3

38 MILES—61.16 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	3.51	17.1	18.1	18.9	19.6	20.3	21.3	22.1	22.9	23.5
954 000		54	7	600 000	3.79	17.3	18.3	19.1	19.8	20.5	21.5	22.3	23.0	23.7
874 500		54	7	550 000	4.14	17.4	18.5	19.3	20.0	20.6	21.7	22.5	23.2	23.8
795 000		54	7	500 000	4.53	17.7	18.7	19.5	20.2	20.8	21.9	22.7	23.4	24.0
715 500		54	7	450 000	5.04	17.9	18.9	19.8	20.5	21.1	22.1	23.0	23.7	24.3
636 000		54	7	400 000	5.68	18.2	19.2	20.0	20.7	21.4	22.4	23.2	23.9	24.6
556 500		30	7	350 000	6.37	18.3	19.3	20.1	20.8	21.5	22.5	23.3	24.0	24.7
477 000		30	7	300 000	7.44	18.6	19.7	20.5	21.2	21.8	22.9	23.7	24.4	25.0
397 500		30	7	250 000	8.92	19.1	20.1	21.0	21.7	22.3	23.3	24.2	24.9	25.5
336 400		30	7	0 000	10.6	19.5	20.5	21.4	22.1	22.7	23.7	24.6	25.3	25.9
266 800		26	7	000	13.3	20.2	21.3	22.1	22.8	23.4	24.5	25.3	26.0	26.6
211 600	0 000	6	1	00	17.6	23.9	24.9	25.7	26.4	27.1	28.1	28.9	29.6	30.2
167 806	000	6	1	0	22.0	24.2	25.3	26.1	26.8	27.4	28.5	29.3	30.0	30.6
133 077	00	6	1	1	27.3	24.6	25.7	26.5	27.2	27.8	28.9	29.7	30.4	31.0
105 535	0	6	1	2	34.0	25.0	26.1	26.9	27.6	28.2	29.3	30.1	30.8	31.4
83 693	1	6	1	3	42.6	25.5	26.5	27.4	28.1	28.7	29.7	30.5	31.2	31.9
66 371	2	6	1	4	53.6	25.9	26.9	27.8	28.5	29.1	30.1	30.9	31.7	32.3
52 635	3	6	1	5	67.5	26.3	27.3	28.2	28.9	29.5	30.5	31.4	32.1	32.7
41 741	4	6	1	6	85.0	26.7	27.7	28.6	29.3	29.9	30.9	31.8	32.5	33.1

40 MILES—64.37 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	3.69	18.0	19.1	19.9	20.7	21.3	22.4	23.3	24.1	24.7
954 000		54	7	600 000	3.99	18.2	19.2	20.1	20.9	21.5	22.6	23.5	24.3	24.9
874 500		54	7	550 000	4.36	18.4	19.4	20.3	21.1	21.7	22.8	23.7	24.4	25.1
795 000		54	7	500 000	4.77	18.6	19.7	20.6	21.3	21.9	23.0	23.9	24.7	25.3
715 500		54	7	450 000	5.30	18.8	19.9	20.8	21.6	22.2	23.3	24.2	24.9	25.6
636 000		54	7	400 000	5.98	19.1	20.2	21.1	21.8	22.5	23.6	24.5	25.2	25.9
556 500		30	7	350 000	6.71	19.2	20.3	21.2	21.9	22.6	23.7	24.6	25.3	26.0
477 000		30	7	300 000	7.83	19.6	20.7	21.6	22.3	23.0	24.1	25.0	25.7	26.3
397 500		30	7	250 000	9.39	20.1	21.2	22.1	22.8	23.5	24.6	25.4	26.2	26.8
336 400		30	7	0 000	11.1	20.5	21.6	22.5	23.2	23.9	25.0	25.9	26.6	27.3
266 800		26	7	000	14.0	21.3	22.4	23.3	24.0	24.7	25.7	[illegible]	27.4	28.0
211 600	0 000	6	1	00	18.6	25.1	26.2	27.1	27.8	28.5	29.6	30.5	31.2	31.8
167 806	000	6	1	0	23.2	25.5	26.6	27.5	28.2	28.9	30.0	30.9	31.6	32.2
133 077	00	6	1	1	28.7	25.9	27.0	27.9	28.7	29.3	30.4	31.3	32.0	32.7
105 535	0	6	1	2	35.7	26.4	27.4	28.3	29.1	29.7	30.8	31.7	32.4	33.1
83 693	1	6	1	3	44.8	26.8	27.9	28.8	29.5	30.2	31.3	32.2	32.9	33.5
66 371	2	6	1	4	56.4	27.2	28.3	29.2	30.0	30.6	31.7	32.6	33.3	34.0
52 635	3	6	1	5	71.0	27.7	28.7	29.6	30.4	31.0	32.1	33.0	33.7	34.4
41 741	4	6	1	6	89.5	28.1	29.2	30.1	30.8	31.5	32.5	33.4	34.2	34.8

42 MILES—67.59 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	3.87	18.9	20.0	20.9	21.7	22.4	23.5	24.5	25.3	25.9
954 000		54	7	600 000	4.19	19.1	20.2	21.1	21.9	22.6	23.7	24.7	25.5	26.1
874 500		54	7	550 000	4.57	19.3	20.4	21.3	22.1	22.8	23.9	24.9	25.7	26.3
795 000		54	7	500 000	5.01	19.5	20.7	21.6	22.4	23.0	24.2	25.1	25.9	26.6
715 500		54	7	450 000	5.57	19.8	20.9	21.9	22.6	23.3	24.5	25.4	26.2	26.8
636 000		54	7	400 000	6.28	20.1	21.2	22.2	22.9	23.6	24.8	25.7	26.5	27.1
556 500		30	7	350 000	7.04	20.2	21.3	22.3	23.0	23.7	24.9	25.8	26.6	27.3
477 000		30	7	300 000	8.22	20.6	21.7	22.7	23.5	24.1	25.3	26.2	27.0	27.7
397 500		30	7	250 000	9.86	21.1	22.3	23.2	24.0	24.6	25.8	26.7	27.5	28.2
336 400		30	7	0 000	11.7	21.6	22.7	23.6	24.4	25.1	26.2	27.2	27.9	28.6
266 800		26	7	000	14.7	22.4	23.5	24.4	25.2	25.9	27.0	28.0	28.7	29.4
211 600	0 000	6	1	00	19.5	26.4	27.5	28.4	29.2	29.9	31.0	32.0	32.7	33.4
167 806	000	6	1	0	24.3	26.8	27.9	28.9	29.6	30.3	31.5	32.4	33.2	33.9
133 077	00	6	1	1	30.2	27.2	28.4	29.3	30.1	30.8	31.9	32.8	33.6	34.3
105 535	0	6	1	2	37.5	27.7	28.8	29.8	30.5	31.2	32.4	33.3	34.1	34.7
83 693	1	6	1	3	47.0	28.2	29.3	30.2	31.0	31.7	32.8	33.8	34.5	35.2
66 371	2	6	1	4	59.2	28.6	29.7	30.7	31.5	32.1	33.3	34.2	35.0	35.7
52 635	3	6	1	5	74.6	29.0	30.2	31.1	31.9	32.6	33.7	34.7	35.4	36.1
41 741	4	6	1	6	94.0	29.5	30.6	31.6	32.4	33.0	34.2	35.1	35.9	36.6

44 MILES—70.81 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	4.06	19.8	21.0	21.9	22.7	23.5	24.7	25.6	26.5	27.2
954 000		54	7	600 000	4.39	20.0	21.2	22.2	23.0	23.7	24.9	25.9	26.7	27.4
874 500		54	7	550 000	4.79	20.2	21.4	22.3	23.2	23.9	25.1	26.1	26.9	27.6
795 000		54	7	500 000	5.25	20.4	21.6	22.6	23.4	24.1	25.3	26.3	27.1	27.8
715 500		54	7	450 000	5.83	20.7	21.9	22.9	23.7	24.4	25.6	26.6	27.4	28.1
636 000		54	7	400 000	6.57	21.0	22.2	23.2	24.0	24.7	25.9	26.9	27.7	28.4
556 500		30	7	350 000	7.38	21.2	22.3	23.3	24.1	24.9	26.0	27.0	27.8	28.6
477 000		30	7	300 000	8.61	21.6	22.8	23.8	24.6	25.3	26.5	27.5	28.3	29.0
397 500		30	7	250 000	10.3	22.1	23.3	24.3	25.1	25.8	27.0	28.0	28.8	29.5
336 400		30	7	0 000	12.2	22.6	23.8	24.8	25.6	26.3	27.5	28.5	29.3	30.0
266 800		26	7	000	15.4	23.4	24.6	25.6	26.4	27.1	28.3	29.3	30.1	30.8
211 600	0 000	6	1	00	20.4	27.6	28.8	29.8	30.6	31.3	32.5	33.5	34.3	35.0
167 806	000	6	1	0	25.5	28.1	29.3	30.2	31.1	31.8	33.0	33.9	34.8	35.5
133 077	00	6	1	1	31.6	28.5	29.7	30.7	31.5	32.2	33.4	34.4	35.2	35.9
105 535	0	6	1	2	39.3	29.0	30.2	31.2	32.0	32.7	33.9	34.9	35.7	36.4
83 693	1	6	1	3	49.3	29.5	30.7	31.7	32.5	33.2	34.4	35.4	36.2	36.9
66 371	2	6	1	4	62.0	30.0	31.2	32.1	32.9	33.7	34.9	35.8	36.6	37.4
52 635	3	6	1	5	78.1	30.4	31.6	32.6	33.4	34.1	35.3	36.3	37.1	37.8
41 741	4	6	1	6	98.4	30.9	32.1	33.1	33.9	34.6	35.8	36.8	37.6	38.3

46 MILES—74.03 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	4.24	20.7	21.9	22.9	23.8	24.5	25.8	26.8	27.7	28.4
954 000		54	7	600 000	4.58	20.9	22.1	23.2	24.0	24.8	26.0	27.0	27.9	28.6
874 500		54	7	550 000	5.01	21.1	22.4	23.4	24.2	25.0	26.2	27.3	28.1	28.8
795 000		54	7	500 000	5.49	21.4	22.6	23.6	24.5	25.2	26.5	27.5	28.4	29.1
715 500		54	7	450 000	6.10	21.7	22.9	23.9	24.8	25.5	26.8	27.8	28.7	29.4
636 000		54	7	400 000	6.87	22.0	23.2	24.3	25.1	25.9	27.1	28.1	29.0	29.7
556 500		30	7	350 000	7.71	22.1	23.4	24.4	25.2	26.0	27.2	28.3	29.1	29.8
477 000		30	7	300 000	9.00	22.6	23.8	24.8	25.7	26.4	27.7	28.7	29.6	30.3
397 500		30	7	250 000	10.8	23.1	24.4	25.4	26.2	27.0	28.2	29.3	30.1	30.9
336 400		30	7	0 000	12.8	23.6	24.9	25.9	26.7	27.5	28.7	29.7	30.6	31.3
266 800		26	7	000	16.1	24.5	25.7	26.8	27.6	28.4	29.6	30.6	31.5	32.2
211 600	0 000	6	1	00	21.4	28.9	30.1	31.2	32.0	32.7	34.0	35.0	35.9	36.6
167 806	000	6	1	0	26.7	29.3	30.6	31.6	32.5	33.2	34.5	35.5	36.3	37.1
133 077	00	6	1	1	33.0	29.8	31.1	32.1	33.0	33.7	35.0	36.0	36.8	37.6
105 535	0	6	1	2	41.1	30.3	31.6	32.6	33.4	34.2	35.4	36.5	37.3	38.1
83 693	1	6	1	3	51.5	30.8	32.1	33.1	34.0	34.7	36.0	37.0	37.8	38.6
66 371	2	6	1	4	64.9	31.3	32.6	33.6	34.4	35.2	36.4	37.5	38.3	39.1
52 635	3	6	1	5	81.7	31.8	33.1	34.1	34.9	35.7	36.9	38.0	38.8	39.5
41 741	4	6	1	6	103.	32.3	33.6	34.6	35.4	36.2	37.4	38.5	39.3	40.0

48 MILES—77.25 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	4.43	21.6	22.9	23.9	24.8	25.6	26.9	28.0	28.9	29.6
954 000		54	7	600 000	4.78	21.8	23.1	24.2	25.1	25.8	27.1	28.2	29.1	29.9
874 500		54	7	550 000	5.23	22.0	23.3	24.4	25.3	26.1	27.4	28.4	29.3	30.1
795 000		54	7	500 000	5.73	22.3	23.6	24.7	25.6	26.3	27.6	28.7	29.6	30.4
715 500		54	7	450 000	6.37	22.6	23.9	25.0	25.9	26.6	27.9	29.0	29.9	30.7
636 000		54	7	400 000	7.17	22.9	24.3	25.3	26.2	27.0	28.3	29.4	30.2	31.0
556 500		30	7	350 000	8.05	23.1	24.4	25.4	26.3	27.1	28.4	29.5	30.4	31.1
477 000		30	7	300 000	9.39	23.5	24.8	25.9	26.8	27.6	28.9	30.0	30.8	31.6
397 500		30	7	250 000	11.3	24.1	25.4	26.5	27.4	28.2	29.5	30.5	31.4	32.2
336 400		30	7	0 000	13.3	24.6	25.9	27.0	27.9	28.7	30.0	31.0	31.9	32.7
266 800		26	7	000	16.8	25.6	26.9	27.9	28.8	29.6	30.9	32.0	32.9	33.6
211 600	0 000	6	1	00	22.3	30.1	31.4	32.5	33.4	34.2	35.5	36.5	37.4	38.2
167 806	000	6	1	0	27.8	30.6	31.9	33.0	33.9	34.7	36.0	37.0	37.9	38.7
133 077	00	6	1	1	34.5	31.1	32.4	33.5	34.4	35.2	36.5	37.5	38.4	39.2
105 535	0	6	1	2	42.9	31.6	32.9	34.0	34.9	35.7	37.0	38.0	38.9	39.7
83 693	1	6	1	3	53.8	32.2	33.5	34.6	35.4	36.2	37.5	38.6	39.5	40.2
66 371	2	6	1	4	67.7	32.7	34.0	35.1	35.9	36.7	38.0	39.1	40.0	40.8
52 635	3	6	1	5	85.3	33.2	34.5	35.6	36.5	37.2	38.5	39.6	40.5	41.3
41 741	4	6	1	6	107.	33.7	35.0	36.1	37.0	37.8	39.1	40.1	41.0	41.8

50 MILES—80.47 Km.

Circular mils (aluminum)	A.W.G. (B&S)	Alum	Steel	Copper equivalent	Total resistance R	2 feet 0.61 m	2.5 feet 0.76 m	3 feet 0.91 m	3.5 feet 1.07 m	4 feet 1.22 m	5 feet 1.52 m	6 feet 1.83 m	7 feet 2.13 m	8 feet 2.44 m
1 033 500		54	7	650 000	4.61	22.5	23.8	24.9	25.9	26.7	28.0	29.1	30.1	30.9
954 000		54	7	600 000	4.98	22.7	24.1	25.2	26.1	26.9	28.3	29.4	30.3	31.1
874 500		54	7	550 000	5.45	22.9	24.3	25.4	26.3	27.2	28.5	29.6	30.5	31.4
795 000		54	7	500 000	5.97	23.2	24.6	25.7	26.6	27.4	28.8	29.9	30.8	31.6
715 500		54	7	450 000	6.63	23.6	24.9	26.0	26.9	27.8	29.1	30.2	31.1	32.0
636 000		54	7	400 000	7.47	23.9	25.3	26.4	27.3	28.1	29.5	30.6	31.5	32.3
556 500		30	7	350 000	8.39	24.0	25.4	26.5	27.4	28.2	29.6	30.7	31.6	32.4
477 000		30	7	300 000	9.79	24.5	25.9	27.0	27.9	28.7	30.1	31.2	32.1	32.9
397 500		30	7	250 000	11.7	25.1	26.5	27.6	28.5	29.3	30.7	31.8	32.7	33.5
336 400		30	7	0 000	13.9	25.7	27.0	28.1	29.1	29.9	31.2	32.3	33.3	34.1
266 800		26	7	000	17.5	26.6	28.0	29.1	30.0	30.8	32.2	33.3	34.2	35.0
211 600	0 000	6	1	00	23.2	31.4	32.7	33.9	34.8	35.6	37.0	38.1	39.0	39.8
167 806	000	6	1	0	29.0	31.9	33.3	34.4	35.3	36.1	37.5	38.6	39.5	40.3
133 077	00	6	1	1	35.9	32.4	33.8	34.9	35.8	36.6	38.0	39.1	40.0	40.8
105 535	0	6	1	2	44.7	33.0	34.3	35.4	36.4	37.2	38.5	39.6	40.6	41.4
83 693	1	6	1	3	56.0	33.5	34.9	36.0	36.9	37.7	39.1	40.2	41.1	41.9
66 371	2	6	1	4	70.5	34.1	35.4	36.5	37.4	38.3	39.6	40.7	41.6	42.5
52 635	3	6	1	5	88.8	34.6	35.9	37.0	38.0	38.8	40.1	41.3	42.2	43.0
41 741	4	6	1	6	112.	35.1	36.5	37.6	38.5	39.3	40.7	41.8	42.7	43.5

These 60 cycle resistances are based upon a temperature of 25° C. (77° F.) and a current density of 600 amperes per square inch as given in table VI. The reactances are based upon all current densities for the multiple layer conductors and upon 600 amperes per square inch for the single layer conductors as given in table XII.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XXXV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

50 MILES—80.47 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS

Circular Mils or A. W. G. (B & S)	3 FEET—.914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.995	.000 904	4.65	27.9	.000 000	.000 387	.995	.000 808	4.65	31.0	.000 000	.000 346	.995	.000 757	4.65	33.0	.000 000	.000 324
600 000	.995	.000 965	5.02	28.2	.000 000	.000 383	.995	.000 865	5.02	31.3	.000 000	.000 343	.995	.000 808	5.02	33.3	.000 000	.000 321
550 000	.995	.001 04	5.44	28.5	.000 000	.000 379	.995	.000 929	5.44	31.5	.000 000	.000 340	.995	.000 870	5.44	33.6	.000 000	.000 318
500 000	.995	.001 12	5.96	28.8	.000 000	.000 375	.995	.001 01	5.96	31.8	.000 000	.000 337	.995	.000 944	5.96	33.9	.000 000	.000 315
450 000	.995	.001 23	6.60	29.1	.000 000	.000 371	.995	.001 10	6.60	32.1	.000 000	.000 333	.995	.001 03	6.60	34.2	.000 000	.000 312
400 000	.995	.001 36	7.39	29.6	.000 000	.000 366	.995	.001 22	7.39	32.6	.000 000	.000 329	.995	.001 15	7.39	34.6	.000 000	.000 309
350 000	.995	.001 53	8.42	30.0	.000 000	.000 361	.995	.001 37	8.42	33.0	.000 000	.000 325	.995	.001 29	8.42	35.0	.000 000	.000 305
300 000	.995	.001 74	9.79	30.4	.000 000	.000 355	.995	.001 58	9.79	33.5	.000 000	.000 320	.995	.001 48	9.79	35.5	.000 000	.000 301
250 000	.995	.002 05	11.7	31.0	.000 000	.000 348	.995	.001 85	11.7	34.1	.000 000	.000 315	.995	.001 74	11.7	36.1	.000 000	.000 296
0 000	.995	.002 37	13.8	31.8	.000 000	.000 341	.995	.002 15	13.8	34.9	.000 000	.000 309	.995	.002 02	13.8	36.9	.000 000	.000 292
000	.995	.002 91	17.4	32.5	.000 000	.000 333	.995	.002 65	17.4	35.6	.000 000	.000 303	.995	.002 50	17.4	37.6	.000 000	.000 286
00	.995	.003 59	21.9	33.2	.000 000	.000 326	.995	.003 26	21.9	36.3	.000 000	.000 297	.995	.003 08	21.9	38.4	.000 000	.000 280
0	.995	.004 43	27.6	33.9	.000 000	.000 319	.995	.004 04	27.6	37.0	.000 000	.000 291	.995	.003 82	27.6	39.1	.000 000	.000 275
1	.995	.005 46	34.8	34.7	−.000 001	.000 312	.995	.004 99	34.8	37.7	.000 000	.000 285	.995	.004 71	34.8	39.8	.000 000	.000 270
2	.995	.006 74	43.9	35.4	−.000 001	.000 305	.995	.006 16	43.9	38.5	−.000 001	.000 280	.995	.005 83	43.9	40.5	−.000 001	.000 265
3	.995	.008 31	55.4	36.1	−.000 001	.000 299	.995	.007 63	55.4	39.2	−.000 001	.000 275	.995	.007 23	55.4	41.3	−.000 001	.000 260
4	.995	.010 3	69.8	36.9	−.000 001	.000 293	.995	.009 43	69.8	40.0	−.000 001	.000 269	.995	.008 96	69.8	42.0	−.000 001	.000 256
5	.995	.012 7	88.1	37.8	−.000 001	.000 288	.995	.011 7	88.1	40.8	−.000 001	.000 264	.995	.011 1	88.1	42.9	−.000 001	.000 251
6	.995	.015 7	111.	38.7	−.000 001	.000 282	.995	.014 5	111.	41.7	−.000 001	.000 260	.995	.013 7	111.	43.7	−.000 001	.000 247

Circular Mils or A. W. G. (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.995	.000 722	4.65	34.6	.000 000	.000 309	.995	.000 696	4.65	35.8	.000 000	.000 298	.995	.000 675	4.65	36.8	.000 000	.000 289
600 000	.995	.000 772	5.02	34.8	.000 000	.000 306	.995	.000 744	5.02	36.1	.000 000	.000 296	.995	.000 723	5.02	37.1	.000 000	.000 287
550 000	.995	.000 831	5.44	35.1	.000 000	.000 304	.995	.000 802	5.44	36.3	.000 000	.000 294	.995	.000 779	5.44	37.3	.000 000	.000 285
500 000	.995	.000 902	5.96	35.4	.000 000	.000 302	.995	.000 871	5.96	36.6	.000 000	.000 291	.995	.000 847	5.96	37.6	.000 000	.000 283
450 000	.995	.000 988	6.60	35.7	.000 000	.000 299	.995	.000 955	6.60	36.9	.000 000	.000 289	.995	.000 929	6.60	37.9	.000 000	.000 281
400 000	.995	.001 10	7.39	36.2	.000 000	.000 296	.995	.001 06	7.39	37.4	.000 000	.000 286	.995	.001 03	7.39	38.4	.000 000	.000 278
350 000	.995	.001 23	8.42	36.6	.000 000	.000 292	.995	.001 19	8.42	37.8	.000 000	.000 282	.995	.001 16	8.42	38.8	.000 000	.000 275
300 000	.995	.001 42	9.79	37.0	.000 000	.000 288	.995	.001 37	9.79	38.3	.000 000	.000 279	.995	.001 33	9.79	39.3	.000 000	.000 271
250 000	.995	.001 67	11.7	37.6	.000 000	.000 284	.995	.001 62	11.7	38.8	.000 000	.000 275	.995	.001 57	11.7	39.8	.000 000	.000 267
0 000	.995	.001 94	13.8	38.4	.000 000	.000 279	.995	.001 87	13.8	39.7	.000 000	.000 270	.995	.001 83	13.8	40.7	.000 000	.000 263
000	.995	.002 40	17.4	39.1	.000 000	.000 274	.995	.002 32	17.4	40.4	.000 000	.000 265	.995	.002 26	17.4	41.4	.000 000	.000 259
00	.995	.002 96	21.9	39.9	.000 000	.000 269	.995	.002 87	21.9	41.1	.000 000	.000 261	.995	.002 80	21.9	42.1	.000 000	.000 254
0	.995	.003 66	27.6	40.6	.000 000	.000 264	.995	.003 55	27.6	41.8	.000 000	.000 256	.995	.003 46	27.6	42.8	.000 000	.000 250
1	.995	.004 53	34.8	41.3	.000 000	.000 259	.995	.004 40	34.8	42.5	.000 000	.000 252	.995	.004 30	34.8	43.5	.000 000	.000 246
2	.995	.005 61	43.9	42.1	.000 000	.000 255	.995	.005 45	43.9	43.3	.000 000	.000 247	.995	.005 32	43.9	44.3	.000 000	.000 241
3	.995	.006 95	55.4	42.8	−.000 001	.000 250	.995	.006 76	55.4	44.0	−.000 001	.000 243	.995	.006 59	55.4	45.0	−.000 001	.000 237
4	.995	.008 63	69.8	43.6	−.000 001	.000 246	.995	.008 38	69.8	44.8	−.000 001	.000 239	.995	.008 19	69.8	45.8	−.000 001	.000 234
5	.995	.010 7	88.1	44.4	−.000 001	.000 242	.995	.010 4	88.1	45.6	−.000 001	.000 235	.995	.010 2	88.1	46.6	−.000 001	.000 230
6	.995	.013 3	111.	45.3	−.000 001	.000 238	.995	.012 9	111.	46.5	−.000 001	.000 232	.995	.012 6	111.	47.4	−.000 001	.000 226

Circular Mils or A. W. G. (B & S)	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.995	.000 660	4.65	37.7	.000 000	.000 283	.995	.000 646	4.65	38.4	.000 000	.000 277	.995	.000 634	4.65	39.1	.000 000	.000 272
600 000	.995	.000 706	5.02	37.9	.000 000	.000 281	.995	.000 691	5.02	38.7	.000 000	.000 275	.995	.000 679	5.02	39.4	.000 000	.000 270
550 000	.995	.000 761	5.44	38.2	.000 000	.000 279	.995	.000 745	5.44	39.0	.000 000	.000 273	.995	.000 733	5.44	39.6	.000 000	.000 268
500 000	.995	.000 826	5.96	38.5	.000 000	.000 276	.995	.000 810	5.96	39.2	.000 000	.000 271	.995	.000 796	5.96	39.9	.000 000	.000 266
450 000	.995	.000 907	6.60	38.8	.000 000	.000 274	.995	.000 889	6.60	39.6	.000 000	.000 269	.995	.000 873	6.60	40.2	.000 000	.000 264
400 000	.995	.001 01	7.39	39.3	.000 000	.000 271	.995	.000 985	7.39	40.0	.000 000	.000 266	.995	.000 969	7.39	40.7	.000 000	.000 261
350 000	.995	.001 13	8.42	39.7	.000 000	.000 268	.995	.001 11	8.42	40.4	.000 000	.000 263	.995	.001 09	8.42	41.1	.000 000	.000 259
300 000	.995	.001 30	9.79	40.1	.000 000	.000 265	.995	.001 28	9.79	40.9	.000 000	.000 260	.995	.001 26	9.79	41.6	.000 000	.000 256
250 000	.995	.001 54	11.7	40.7	.000 000	.000 261	.995	.001 51	11.7	41.5	.000 000	.000 256	.995	.001 48	11.7	42.1	.000 000	.000 252
0 000	.995	.001 79	13.8	41.5	.000 000	.000 258	.995	.001 75	13.8	42.3	.000 000	.000 253	.995	.001 73	13.8	43.0	.000 000	.000 249
000	.995	.002 21	17.4	42.2	.000 000	.000 253	.995	.002 17	17.4	43.0	.000 000	.000 248	.995	.002 13	17.4	43.7	.000 000	.000 244
00	.995	.002 74	21.9	42.9	.000 000	.000 249	.995	.002 69	21.9	43.7	.000 000	.000 244	.995	.002 64	21.9	44.4	.000 000	.000 240
0	.995	.003 39	27.6	43.7	.000 000	.000 245	.995	.003 33	27.6	44.5	.000 000	.000 240	.995	.003 28	27.6	45.1	.000 000	.000 236
1	.995	.004 20	34.8	44.4	.000 000	.000 240	.995	.004 13	34.8	45.2	.000 000	.000 236	.995	.004 07	34.8	45.8	.000 000	.000 233
2	.995	.005 22	43.9	45.1	.000 000	.000 237	.995	.005 12	43.9	45.9	.000 000	.000 232	.995	.005 04	43.9	46.5	.000 000	.000 229
3	.995	.006 47	55.4	45.9	−.000 001	.000 233	.995	.006 36	55.4	46.6	.000 000	.000 229	.995	.006 26	55.4	47.3	.000 000	.000 225
4	.995	.008 03	69.8	46.7	−.000 001	.000 229	.995	.007 89	69.8	47.4	−.000 001	.000 225	.995	.007 77	69.8	48.0	−.000 001	.000 222
5	.995	.009 97	88.1	47.5	−.000 001	.000 226	.995	.009 80	88.1	48.2	−.000 001	.000 222	.995	.009 67	88.1	48.8	−.000 001	.000 219
6	.995	.012 4	111.	48.3	−.000 001	.000 222	.995	.012 2	111.	49.1	−.000 001	.000 218	.995	.012 0	111.	49.7	−.000 001	.000 215

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XXXVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

50 MILES—80.47 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

Circular mils or A. W. G. (B. & S.)	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	3 Feet— .914 Meter						5 Feet—1.524 Meters						7 Feet—2.134 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.995	.000 956	4.59	24.9	.000 000	.000 415	.995	.000 849	4.59	28.0	.000 000	.000 368	.995	.000 791	4.59	30.0	.000 000	.000 343
954 000	600 000	.995	.001 02	4.97	25.1	.000 000	.000 411	.995	.000 910	4.97	28.2	.000 000	.000 365	.995	.000 849	4.97	30.3	.000 000	.000 341
874 500	550 000	.995	.001 11	5.43	25.4	.000 000	.000 406	.995	.000 986	5.43	28.5	.000 000	.000 362	.995	.000 920	5.43	30.5	.000 000	.000 338
795 000	500 000	.995	.001 20	5.93	25.7	.000 000	.000 402	.995	.001 07	5.93	28.8	.000 000	.000 358	.995	.000 994	5.93	30.8	.000 000	.000 334
715 500	450 000	.995	.001 32	6.63	26.0	.000 000	.000 397	.995	.001 18	6.63	29.1	.000 000	.000 354	.995	.001 10	6.63	31.1	.000 000	.000 331
636 000	400 000	.995	.001 46	7.43	26.3	.000 000	.000 391	.995	.001 30	7.43	29.4	.000 000	.000 350	.995	.001 22	7.43	31.5	.000 000	.000 327
556 500	350 000	.995	.001 64	8.37	26.5	.000 000	.000 389	.995	.001 46	8.37	29.6	.000 000	.000 348	.995	.001 37	8.37	31.6	.000 000	.000 326
477 000	300 000	.995	.001 87	9.77	27.0	.000 000	.000 382	.995	.001 68	9.77	30.1	.000 000	.000 343	.995	.001 57	9.77	32.1	.000 000	.000 321
397 500	250 000	.995	.002 20	11.7	27.6	.000 000	.000 374	.995	.001 98	11.7	30.7	.000 000	.000 337	.995	.001 85	11.7	32.7	.000 000	.000 315
336 400	0 000	.995	.002 56	13.9	28.1	.000 000	.000 368	.995	.002 30	13.9	31.2	.000 000	.000 331	.995	.002 16	13.9	33.2	.000 000	.000 311
266 800	000	.995	.003 11	17.4	29.1	.000 000	.000 355	.995	.002 80	17.4	32.2	.000 000	.000 321	.995	.002 64	17.4	34.2	.000 000	.000 302
0 000	00	.994	.004 03	23.1	33.8	.000 000	.000 347	.994	.003 64	23.1	36.9	.000 000	.000 314	.994	.003 43	23.1	39.0	.000 000	.000 296
000	0	.994	.004 91	28.8	34.3	–.000 001	.000 339	.994	.004 44	28.8	37.4	.000 000	.000 307	.994	.004 19	28.8	39.5	.000 000	.000 290
00	1	.994	.005 94	35.8	34.9	–.000 001	.000 331	.994	.005 40	35.8	38.0	–.000 001	.000 301	.994	.005 10	35.8	40.0	.000 000	.000 284
0	2	.994	.007 22	44.5	35.5	–.000 001	.000 323	.994	.006 58	44.5	38.5	–.000 001	.000 295	.994	.006 22	44.5	40.6	–.000 001	.000 279
1	3	.994	.008 86	55.8	36.1	–.000 001	.000 316	.994	.008 09	55.8	39.2	–.000 001	.000 289	.994	.007 65	55.8	41.2	–.000 001	.000 273
2	4	.994	.0109	70.2	36.7	–.000 001	.000 310	.994	.009 98	70.2	39.8	–.000 001	.000 283	.994	.009 45	70.2	41.8	–.000 001	.000 268
3	5	.994	.013 5	88.7	37.4	–.000 001	.000 304	.994	.012 4	88.7	40.5	–.000 001	.000 278	.994	.011 7	88.7	42.4	–.000 001	.000 263
4	6	.994	.0166	112.	38.2	–.000 002	.000 297	.994	.015 3	112.	41.2	–.000 001	.000 273	.994	.014 5	112.	43.2	–.000 001	.000 259

Circular mils or A. W. G. (B. & S.)	Copper equivalent	9 Feet—2.743 Meters						11 Feet—3.353 Meters						13 Feet—3.962 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.995	.000 753	4.59	31.6	.000 000	.000 327	.995	.000 724	4.59	32.8	.000 000	.000 314	.995	.000 702	4.59	33.8	.000 000	.000 305
954 000	600 000	.995	.000 808	4.97	31.8	.000 000	.000 324	.995	.000 778	4.97	33.0	.000 000	.000 312	.995	.000 754	4.97	34.0	.000 000	.000 303
874 500	550 000	.995	.000 875	5.43	32.0	.000 000	.000 321	.995	.000 842	5.43	33.3	.000 000	.000 309	.995	.000 818	5.43	34.3	.000 000	.000 300
795 000	500 000	.995	.000 948	5.93	32.3	.000 000	.000 319	.995	.000 912	5.93	33.5	.000 000	.000 307	.995	.000 885	5.93	34.5	.000 000	.000 298
715 500	450 000	.995	.001 05	6.63	32.6	.000 000	.000 315	.995	.001 01	6.63	33.9	.000 000	.000 304	.995	.000 979	6.63	34.8	.000 000	.000 295
636 000	400 000	.995	.001 16	7.43	33.0	.000 000	.000 312	.995	.001 12	7.43	34.2	.000 000	.000 301	.995	.001 09	7.43	35.2	.000 000	.000 292
556 500	350 000	.995	.001 30	8.37	33.2	.000 000	.000 311	.995	.001 26	8.37	34.3	.000 000	.000 299	.995	.001 22	8.37	35.3	.000 000	.000 291
477 000	300 000	.995	.001 50	9.77	33.6	.000 000	.000 306	.995	.001 45	9.77	34.8	.000 000	.000 295	.995	.001 41	9.77	35.8	.000 000	.000 287
397 500	250 000	.995	.001 77	11.7	34.2	.000 000	.000 301	.995	.001 71	11.7	35.5	.000 000	.000 291	.995	.001 66	11.7	36.5	.000 000	.000 283
336 400	0 000	.995	.002 06	13.9	34.8	.000 000	.000 297	.995	.001 99	13.9	36.0	.000 000	.000 287	.995	.001 94	13.9	37.0	.000 000	.000 279
266 800	000	.995	.002 53	17.4	35.7	.000 000	.000 289	.995	.002 44	17.4	36.9	.000 000	.000 279	.995	.002 38	17.4	38.0	.000 000	.000 272
0 000	00	.994	.003 28	23.1	40.5	.000 000	.000 283	.994	.003 17	23.1	41.7	.000 000	.000 274	.994	.003 09	23.1	42.7	.000 000	.000 267
000	0	.994	.004 02	28.8	41.0	.000 000	.000 278	.994	.003 89	28.8	42.2	.000 000	.000 269	.994	.003 79	28.8	43.2	.000 000	.000 262
00	1	.994	.004 89	35.8	41.5	.000 000	.000 273	.994	.004 73	35.8	42.7	.000 000	.000 264	.994	.004 62	35.8	43.8	.000 000	.000 257
0	2	.994	.005 96	44.5	42.1	–.000 001	.000 267	.994	.005 78	44.5	43.3	–.000 001	.000 259	.994	.005 64	44.5	44.3	.000 000	.000 253
1	3	.994	.007 35	55.8	42.7	–.000 001	.000 263	.994	.007 13	55.8	43.9	–.000 001	.000 255	.994	.006 95	55.8	45.0	–.000 001	.000 248
2	4	.994	.009 08	70.2	43.3	–.000 001	.000 258	.994	.008 82	70.2	44.5	–.000 001	.000 250	.994	.008 61	70.2	45.5	–.000 001	.000 244
3	5	.994	.011 3	88.7	44.0	–.000 001	.000 253	.994	.010 9	88.7	45.1	–.000 001	.000 246	.994	.010 7	88.7	46.2	–.000 001	.000 240
4	6	.994	.014 0	112.	44.7	–.000 001	.000 249	.994	.013 5	112.	45.9	–.000 001	.000 242	.994	.013 2	112.	46.9	–.000 001	.000 236

Circular mils or A. W. G. (B. & S.)	Copper equivalent	15 Feet—4.572 Meters						17 Feet—5.182 Meters						19 Feet—5.791 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.995	.000 685	4.59	34.6	.000 000	.000 297	.995	.000 670	4.59	35.4	.000 000	.000 291	.995	.000 657	4.59	36.0	.000 000	.000 285
954 000	600 000	.995	.000 735	4.97	34.9	.000 000	.000 295	.995	.000 719	4.97	35.6	.000 000	.000 289	.995	.000 706	4.97	36.3	.000 000	.000 283
874 500	550 000	.995	.000 797	5.43	35.1	.000 000	.000 293	.995	.000 781	5.43	35.9	.000 000	.000 287	.995	.000 766	5.43	36.5	.000 000	.000 281
795 000	500 000	.995	.000 863	5.93	35.4	.000 000	.000 290	.995	.000 845	5.93	36.1	.000 000	.000 284	.995	.000 830	5.93	36.8	.000 000	.000 279
715 500	450 000	.995	.000 956	6.63	35.7	.000 000	.000 288	.995	.000 936	6.63	36.5	.000 000	.000 282	.995	.000 920	6.63	37.1	.000 000	.000 277
636 000	400 000	.995	.001 06	7.43	36.1	.000 000	.000 285	.995	.001 04	7.43	36.8	.000 000	.000 279	.995	.001 02	7.43	37.5	.000 000	.000 274
556 500	350 000	.995	.001 19	8.37	36.2	.000 000	.000 284	.995	.001 17	8.37	37.0	.000 000	.000 278	.995	.001 15	8.37	37.6	.000 000	.000 273
477 000	300 000	.995	.001 37	9.77	36.7	.000 000	.000 280	.995	.001 34	9.77	37.4	.000 000	.000 274	.995	.001 32	9.77	38.1	.000 000	.000 270
397 500	250 000	.995	.001 62	11.7	37.3	.000 000	.000 276	.995	.001 59	11.7	38.1	.000 000	.000 270	.995	.001 56	11.7	38.8	.000 000	.000 266
336 400	0 000	.995	.001 89	13.9	37.9	.000 000	.000 272	.995	.001 85	13.9	38.6	.000 000	.000 267	.995	.001 82	13.9	39.3	.000 000	.000 262
266 800	000	.995	.002 32	17.4	38.8	.000 000	.000 265	.995	.002 28	17.4	39.6	.000 000	.000 260	.995	.002 24	17.4	40.3	.000 000	.000 256
0 000	00	.994	.003 02	23.1	43.5	.000 000	.000 261	.994	.002 97	23.1	44.3	.000 000	.000 256	.994	.002 91	23.1	45.0	.000 000	.000 251
000	0	.994	.003 71	28.8	44.1	.000 000	.000 256	.994	.003 63	28.8	44.9	.000 000	.000 251	.994	.003 58	28.8	45.5	.000 000	.000 247
00	1	.994	.004 52	35.8	44.6	.000 000	.000 252	.994	.004 44	35.8	45.4	.000 000	.000 247	.994	.004 36	35.8	46.1	.000 000	.000 243
0	2	.994	.005 52	44.5	45.2	.000 000	.000 247	.994	.005 42	44.5	46.0	.000 000	.000 243	.994	.005 33	44.5	46.6	.000 000	.000 239
1	3	.994	.006 81	55.8	45.8	–.000 001	.000 243	.994	.006 68	55.8	46.5	–.000 001	.000 239	.994	.006 58	55.8	47.2	–.000 001	.000 235
2	4	.994	.008 43	70.2	46.4	–.000 001	.000 239	.994	.008 29	70.2	47.2	–.000 001	.000 235	.994	.008 15	70.2	47.8	–.000 001	.000 231
3	5	.994	.010 5	88.7	47.0	–.000 001	.000 235	.994	.010 3	88.7	47.8	–.000 001	.000 231	.994	.010 1	88.7	48.5	–.000 001	.000 228
4	6	.994	.013 0	112.	47.7	–.000 001	.000 232	.994	.012 7	112.	48.5	–.000 001	.000 228	.994	.012 6	112.	49.2	–.000 001	.000 224

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XXXVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

55 MILES—88.51 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	3 FEET— .914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.993	.001 09	5.12	30.7	.000 000	.000 426	.993	.000 978	5.12	34.1	.000 000	.000 381	.994	.000 916	5.12	36.4	.000 000	.000 356
600 000	.993	.001 17	5.51	31.0	.000 000	.000 422	.993	.001 05	5.51	34.4	.000 000	.000 378	.994	.000 978	5.51	36.7	.000 000	.000 353
550 000	.993	.001 25	5.99	31.3	.000 000	.000 417	.993	.001 12	5.99	34.7	.000 000	.000 374	.994	.001 05	5.99	37.0	.000 000	.000 350
500 000	.993	.001 36	6.56	31.6	.000 000	.000 413	.993	.001 22	6.56	35.0	.000 000	.000 371	.994	.001 14	6.56	37.3	.000 000	.000 347
450 000	.993	.001 49	7.25	32.0	.000 000	.000 408	.993	.001 34	7.25	35.4	.000 000	.000 367	.994	.001 25	7.25	37.6	.000 000	.000 344
400 000	.993	.001 64	8.13	32.5	.000 000	.000 402	.993	.001 48	8.13	35.9	.000 000	.000 362	.994	.001 39	8.13	38.1	.000 000	.000 340
350 000	.993	.001 85	9.25	33.0	.000 000	.000 397	.993	.001 66	9.25	36.4	.000 000	.000 357	.994	.001 56	9.25	38.6	.000 000	.000 336
300 000	.993	.002 11	10.8	33.5	.000 000	.000 390	.993	.001 91	10.8	36.9	.000 000	.000 352	.994	.001 79	10.8	39.1	.000 000	.000 331
250 000	.993	.002 48	12.9	34.1	.000 000	.000 383	.993	.002 24	12.9	37.5	.000 000	.000 346	.994	.002 11	12.9	39.7	.000 000	.000 326
0 000	.993	.002 87	15.2	35.0	.000 000	.000 376	.993	.002 60	15.2	38.4	.000 000	.000 340	.993	.002 45	15.2	40.6	.000 000	.000 321
000	.993	.003 53	19.1	35.8	.000 000	.000 367	.993	.003 20	19.1	39.2	.000 000	.000 333	.993	.003 02	19.1	41.4	.000 000	.000 314
00	.993	.004 34	24.1	36.6	-.000 001	.000 359	.993	.003 95	24.1	40.0	.000 000	.000 326	.993	.003 73	24.1	42.2	.000 000	.000 308
0	.993	.005 35	30.4	37.3	-.000 001	.000 351	.993	.004 89	30.4	40.7	-.000 001	.000 320	.993	.004 62	30.4	43.0	.000 000	.000 303
1	.993	.006 60	38.3	38.1	-.000 001	.000 343	.993	.006 03	38.3	41.5	-.000 001	.000 314	.993	.005 70	38.3	43.8	-.000 001	.000 297
2	.993	.008 15	48.3	38.9	-.000 001	.000 336	.993	.007 46	48.3	42.4	-.000 001	.000 308	.993	.007 06	48.3	44.6	-.000 001	.000 291
3	.993	.010 1	60.9	39.8	-.000 001	.000 329	.993	.009 24	60.9	43.2	-.000 001	.000 302	.993	.008 75	60.9	45.4	-.000 001	.000 286
4	.993	.012 4	76.8	40.7	-.000 001	.000 322	.993	.011 4	76.8	44.1	-.000 001	.000 296	.993	.010 8	76.8	46.3	-.000 001	.000 281
5	.993	.015 4	96.8	41.6	-.000 002	.000 316	.993	.014 1	96.8	45.0	-.000 001	.000 290	.993	.013 4	96.8	47.2	-.000 001	.000 276
6	.993	.019 0	122.	42.7	-.000 002	.000 310	.993	.017 5	122.	46.0	-.000 002	.000 286	.993	.016 6	122.	48.2	-.000 002	.000 271

CIRCULAR MILS OR A W G (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.994	.000 873	5.12	38.0	.000 000	.000 340	.994	.000 842	5.12	39.4	.000 000	.000 328	.994	.000 817	5.12	40.5	.000 000	.000 318
600 000	.994	.000 934	5.51	38.3	.000 000	.000 337	.994	.000 900	5.51	39.7	.000 000	.000 325	.994	.000 874	5.51	40.8	.000 000	.000 316
550 000	.994	.001 01	5.99	38.7	.000 000	.000 334	.994	.000 971	5.99	40.0	.000 000	.000 323	.994	.000 942	5.99	41.1	.000 000	.000 314
500 000	.994	.001 09	6.56	38.9	.000 000	.000 332	.994	.001 05	6.56	40.3	.000 000	.000 320	.994	.001 03	6.56	41.4	.000 000	.000 311
450 000	.994	.001 20	7.25	39.3	.000 000	.000 328	.994	.001 16	7.25	40.6	.000 000	.000 317	.994	.001 12	7.25	41.7	.000 000	.000 309
400 000	.994	.001 33	8.13	39.8	.000 000	.000 325	.994	.001 28	8.13	41.1	.000 000	.000 314	.994	.001 25	8.13	42.2	.000 000	.000 305
350 000	.994	.001 49	9.25	40.3	.000 000	.000 321	.994	.001 44	9.25	41.6	.000 000	.000 310	.994	.001 40	9.25	42.7	.000 000	.000 302
300 000	.994	.001 71	10.8	40.8	.000 000	.000 317	.994	.001 66	10.8	42.1	.000 000	.000 306	.994	.001 61	10.8	43.2	.000 000	.000 298
250 000	.994	.002 02	12.9	41.4	.000 000	.000 312	.994	.001 96	12.9	42.7	.000 000	.000 302	.994	.001 90	12.9	43.8	.000 000	.000 294
0 000	.993	.002 34	15.2	42.3	.000 000	.000 307	.993	.002 27	15.2	43.7	.000 000	.000 297	.994	.002 21	15.2	44.8	.000 000	.000 289
000	.993	.002 90	19.1	43.1	.000 000	.000 301	.993	.002 80	19.1	44.4	.000 000	.000 292	.994	.002 73	19.1	45.5	.000 000	.000 284
00	.993	.003 58	24.1	43.9	.000 000	.000 296	.993	.003 47	24.1	45.2	.000 000	.000 287	.994	.003 38	24.1	46.3	.000 000	.000 279
0	.993	.004 43	30.4	44.6	.000 000	.000 290	.993	.004 30	30.4	46.0	.000 000	.000 282	.994	.004 19	30.4	47.1	.000 000	.000 275
1	.993	.005 48	38.3	45.4	-.000 001	.000 285	.993	.005 32	38.3	46.8	.000 000	.000 277	.994	.005 20	38.3	47.9	.000 000	.000 270
2	.993	.006 79	48.3	46.3	-.000 001	.000 280	.993	.006 59	48.3	47.6	-.000 001	.000 272	.994	.006 43	48.3	48.7	-.000 001	.000 265
3	.993	.008 41	60.9	47.1	-.000 001	.000 275	.993	.008 18	60.9	48.4	-.000 001	.000 267	.994	.007 98	60.9	49.5	-.000 001	.000 261
4	.993	.010 4	76.8	48.0	-.000 001	.000 271	.993	.010 1	76.8	49.3	-.000 001	.000 263	.994	.009 91	76.8	50.4	-.000 001	.000 257
5	.993	.013 0	96.8	48.9	-.000 001	.000 266	.993	.012 6	96.8	50.2	-.000 001	.000 259	.994	.012 3	96.8	51.3	-.000 001	.000 253
6	.993	.016 1	122.	49.9	-.000 001	.000 262	.993	.015 6	122.	51.2	-.000 001	.000 255	.994	.015 3	122.	52.3	-.000 001	.000 249

CIRCULAR MILS OR A W G (B & S)	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.994	.000 799	5.12	41.5	.000 000	.000 311	.994	.000 782	5.12	42.3	.000 000	.000 304	.994	.000 768	5.12	43.0	.000 000	.000 299
600 000	.994	.000 855	5.51	41.7	.000 000	.000 309	.994	.000 836	5.51	42.6	.000 000	.000 302	.994	.000 821	5.51	43.3	.000 000	.000 297
550 000	.994	.000 921	5.99	42.1	.000 000	.000 306	.994	.000 901	5.99	42.9	.000 000	.000 300	.994	.000 886	5.99	43.6	.000 000	.000 295
500 000	.994	.001 00	6.56	42.3	.000 000	.000 304	.994	.000 980	6.56	43.2	.000 000	.000 298	.994	.000 963	6.56	43.9	.000 000	.000 293
450 000	.994	.001 10	7.25	42.7	.000 000	.000 301	.994	.001 08	7.25	43.5	.000 000	.000 295	.994	.001 06	7.25	44.3	.000 000	.000 290
400 000	.994	.001 22	8.13	43.2	.000 000	.000 298	.994	.001 19	8.13	44.0	.000 000	.000 292	.994	.001 17	8.13	44.8	.000 000	.000 287
350 000	.994	.001 37	9.25	43.7	.000 000	.000 295	.994	.001 35	9.25	44.5	.000 000	.000 289	.994	.001 32	9.2[illegible]	45.3	.000 000	.000 284
300 000	.994	.001 58	10.8	44.2	.000 000	.000 292	.994	.001 54	10.8	45.0	.000 000	.000 286	.994	.001 52	10.8	45.8	.000 000	.000 281
250 000	.994	.001 86	12.9	44.8	.000 000	.000 287	.994	.001 82	12.9	45.6	.000 000	.000 282	.994	.001 80	12.9	46.4	.000 000	.000 277
0 000	.994	.002 16	15.2	45.7	.000 000	.000 283	.994	.002 12	15.2	46.5	.000 000	.000 278	.994	.002 09	15.2	47.3	.000 000	.000 273
000	.994	.002 68	19.1	46.5	.000 000	.000 278	.994	.002 62	19.1	47.3	.000 000	.000 273	.994	.002 58	19.1	48.1	.000 000	.000 269
00	.994	.003 31	24.1	47.3	.000 000	.000 273	.994	.003 25	24.1	48.1	.000 000	.000 269	.994	.003 20	24.1	48.8	.000 000	.000 264
0	.994	.004 11	30.4	48.0	.000 000	.000 269	.994	.004 03	30.4	48.9	.000 000	.000 264	.994	.003 96	30.4	49.6	.000 000	.000 260
1	.994	.005 08	38.3	48.8	.000 000	.000 264	.994	.005 00	38.3	49.7	.000 000	.000 260	.994	.004 92	38.3	50.4	.000 000	.000 256
2	.994	.006 31	48.3	49.6	-.000 001	.000 260	.994	.006 19	48.3	50.5	-.000 001	.000 255	.994	.006 10	48.3	51.2	-.000 001	.000 251
3	.994	.007 83	60.9	50.5	-.000 001	.000 256	.994	.007 69	60.9	51.3	-.000 001	.000 251	.994	.007 57	60.9	52.0	-.000 001	.000 248
4	.994	.009 72	76.8	51.4	-.000 001	.000 252	.994	.009 55	76.8	52.2	-.000 001	.000 248	.994	.009 40	76.8	52.9	-.000 001	.000 244
5	.994	.012 1	96.8	52.3	-.000 001	.000 248	.994	.011 9	96.8	53.1	-.000 001	.000 244	.994	.011 7	96.8	53.8	-.000 001	.000 241
6	.994	.015 0	122.	53.3	-.000 001	.000 244	.994	.014 7	122.	54.1	-.000 001	.000 240	.994	.014 5	122.	54.8	-.000 001	.000 237

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XXXVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

55 MILES—88.51 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	3 FEET— .914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.994	.001 16	5.05	27.3	.000000	.000456	.994	.001 03	5.05	30.7	.000 000	.000 405	.994	.000 956	5.05	33.0	.000 000	.000 377
954 000	600 000	.994	.001 24	5.46	27.6	.000000	.000452	.994	.001 10	5.46	31.0	.000 000	.000 401	.994	.001 03	5.46	33.3	.000 000	.000 374
874 500	550 000	.994	.001 34	5.97	27.9	.000000	.000 447	.994	.001 19	5.97	31.3	.000000	.000 398	.994	.001 11	5.97	33.5	.000 000	.000 371
795 000	500 000	.994	.001 45	6.52	28.2	.000000	.000 442	.994	.001 29	6.52	31.6	.000 000	.000 394	.994	.001 20	6.52	33.8	.000000	.000 367
715 500	450 000	.994	.001 60	7.28	28.5	.000000	.000436	.994	.001 42	7.28	32.0	.000 000	.000 389	.994	.001 33	7.28	34.2	.000000	.000 363
636 000	400 000	.994	.001 76	8.16	28.9	.000000	.000 430	.994	.001 58	8.16	32.3	.000000	.000 385	.994	.001 47	8.16	34.6	.000000	.000 360
556 500	350 000	.994	.001 98	9.20	29.1	.000 000	.000428	.994	.001 77	9.20	32.5	.000 000	.000 383	.994	.001 65	9.20	34.8	.000000	.000 358
477 000	300 000	.994	.002 27	10.7	29.7	.000000	.000421	.994	.002 03	10.7	33.1	.000000	.000377	.994	.001 90	10.7	35.3	.000000	.000 352
397 500	250 000	.994	.002 66	12.9	30.3	.000 000	.000412	.994	.002 39	12.9	33.7	.000000	.000 370	.994	.002 24	12.9	36.0	.000000	.000346
336 400	0 000	.994	.003 09	15.2	30.9	.000000	.000 405	.994	.002 78	15.2	34.3	.000000	.000 364	.994	.002 61	15.2	36.5	.000 000	.000 341
266 800	000	.994	.003 76	19.2	32.0	.000000	.000 391	.994	.003 39	19.2	35.4	.000000	.000 352	.994	.003 19	19.2	37.6	.000000	.000 332
0 000	00	.993	.004 87	25.4	37.2	-.000001	.000 381	.993	.004 41	25.4	40.6	-.000 001	.000 345	.993	.004 15	25.4	42.8	-.000000	.000 325
000	0	.993	.005 93	31.7	37.8	-.000001	.000 373	.993	.005 37	31.7	41.2	-.000001	.000 338	.993	.005 07	31.7	43.4	-.000001	.000 318
00	1	.993	.007 18	39.3	38.4	-.000001	.000 364	.993	.006 53	39.3	41.8	-.000001	.000 331	.993	.006 16	39.3	44.0	-.000001	.000 312
0	2	.993	.008 73	48.9	39.0	-.000001	.000 356	.993	.007 95	48.9	42.4	-.000 001	.000 324	.993	.007 52	48.9	44.6	-.000001	.000306
1	3	.993	.010 7	61.3	39.7	-.000 001	.000 348	.993	.009 79	61.3	43.1	-.000001	.000 318	.993	.009 24	61.3	45.3	-.000001	.000300
2	4	.993	.013 2	77.2	40.4	-.000002	.000 341	.993	.012 1	77.2	43.8	-.000001	.000 311	.993	.011 4	77.2	46.0	-.000001	.000 295
3	5	.993	.016 3	97.5	41.2	-.000002	.000 334	.993	.015 0	97.5	44.6	-.000002	.000 306	.993	.014 2	97.5	46.7	-.000001	.000 289
4	6	.993	.020 1	123.	42.1	-.000002	.000 327	.993	.018 5	123.	45.4	-.000002	.000 300	.993	.017 5	123.	47.6	-.000002	.000 284

		9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.994	.000 910	5.05	34.7	.000000	.000 359	.994	.000 875	5.05	36.0	.000 000	.000 345	.994	.000 849	5.05	37.1	.000 000	.000 335
954 000	600 000	.994	.000 977	5.46	35.0	.000000	.000 356	.994	.000 940	5.46	36.3	.000 000	.000 343	.994	.000 912	5.46	37.4	.000 000	.000 333
874 500	550 000	.994	.001 06	5.97	35.2	.000000	.000 353	.994	.001 02	5.97	36.6	.000 000	.000 340	.994	.000 989	5.97	37.7	.000 000	.000 330
795 000	500 000	.994	.001 15	6.52	35.5	.000 000	.000 350	.994	.001 10	6.52	36.8	.000 000	.000 337	.994	.001 07	6.52	38.0	.000000	.000 327
715 500	450 000	.994	.001 27	7.28	35.8	.000000	.000 346	.994	.001 22	7.28	37.2	.000000	.000334	.994	.001 18	7.28	38.3	.000 000	.000 324
636 000	400 000	.994	.001 40	8.16	36.3	.000000	.000 343	.994	.001 35	8.16	37.6	.000 000	.000 330	.994	.001 31	8.16	38.7	.000 000	.000 321
556 500	350 000	.994	.001 58	9.20	36.5	.000000	.000 341	.994	.001 52	9.20	37.8	.000000	.000 329	.994	.001 48	9.20	38.9	.000000	.000 320
477 000	300 000	.994	.001 81	10.7	37.0	.000000	.000 337	.994	.001 75	10.7	38.3	.000000	.000 324	.994	.001 70	10.7	39.4	.000000	.000 316
397 500	250 000	.994	.002 14	12.9	37.6	.000 000	.000 331	.994	.002 06	12.9	39.0	.000000	.000 320	.994	.002 01	12.9	40.1	.000000	.000 311
336 400	0 000	.994	.002 49	15.2	38.2	.000 000	.000 326	.994	.002 41	15.2	39.5	.000 000	.000 315	.994	.002 34	15.2	40.6	.000000	.000 306
266 800	000	.994	.003 05	19.2	39.3	.000000	.000 317	.994	.002 95	19.2	40.6	.000 000	.000 306	.994	.002 87	19.2	41.7	.000000	.000 299
0 000	00	.993	.003 97	25.4	44.5	.000000	.000 311	.993	.003 84	25.4	45.9	.000 000	.000 301	.993	.003 74	25.4	46.9	.000000	.000 293
000	0	.993	.004 86	31.7	45.0	.000000	.000 305	.993	.004 70	31.7	46.4	.000 000	.000 295	.993	.004 58	31.7	47.5	.000 000	.000 288
00	1	.993	.005 92	39.3	45.7	.000001	.000 300	.993	.005 72	39.3	47.0	-.000 001	.000 290	.993	.005 58	39.3	48.1	-.000 001	.000 283
0	2	.993	.007 21	48.9	46.3	-.000 001	.000 294	.993	.006 99	48.9	47.6	-.000 001	.000 285	.993	.006 82	48.9	48.7	-.000 001	.000 278
1	3	.993	.008 89	61.3	47.0	-.000001	.000 289	.993	.008 62	61.3	48.3	-.000 001	.000 280	.993	.008 40	61.3	49.5	-.000001	.000 273
2	4	.993	.011 0	77.2	47.6	-.000001	.000 283	.993	.010 7	77.2	49.0	-.000001	.000 275	.993	.010 4	77.2	50.1	-.000001	.000 268
3	5	.993	.013 6	97.5	48.4	-.000001	.000 278	.993	.013 2	97.5	49.7	-.000 001	.000 270	.993	.012 9	97.5	50.9	-.000 001	.000 264
4	6	.993	.016 9	123.	49.3	-.000 002	.000 274	.993	.016 4	123.	50.6	-.000 001	.000 266	.993	.016 0	123.	51.7	-.000001	.000 260

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.994	.000 828	5.05	38.1	.000 000	.000 327	.994	.000 810	5.05	38.9	.000000	.000 320	.994	.000 795	5.05	39.6	.000 000	.000 313
954 000	600 000	.994	.000 889	5.46	38.4	.000000	.000 324	.994	.000 870	5.46	39.2	.000000	.000 317	.994	.000 853	5.46	39.9	.000 000	.000 311
874 500	550 000	.994	.000 964	5.97	38.6	.000000	.000 322	.994	.000 944	5.97	39.5	.000000	.000 315	.994	.000 926	5.97	40.2	.000 000	.000 309
795 000	500 000	.994	.001 04	6.52	38.9	.000000	.000 319	.994	.001 02	6.52	39.7	.000000	.000 312	.994	.001 00	6.52	40.5	.000000	.000 307
715 500	450 000	.994	.001 16	7.28	39.3	.000000	.000 316	.994	.001 13	7.28	40.1	.000000	.000 310	.994	.001 11	7.28	40.8	.000000	.000 304
636 000	400 000	.994	.001 28	8.16	39.7	.000000	.000 313	.994	.001 26	8.16	40.5	.000000	.000 307	.994	.001 23	8.16	41.2	.000000	.000 301
556 500	350 000	.994	.001 44	9.20	39.9	.000000	.000 312	.994	.001 41	9.20	40.7	.000000	.000 305	.994	.001 38	9.20	41.4	.000000	.000 300
477 000	300 000	.994	.001 66	10.7	40.4	.000000	.000 308	.994	.001 62	10.7	41.2	.000000	.000 301	.994	.001 60	10.7	42.0	.000000	.000 296
397 500	250 000	.994	.001 96	12.9	41.0	.000000	.000 303	.994	.001 92	12.9	41.8	.000000	.000 297	.994	.001 89	12.9	42.6	.000000	.000 292
336 400	0 000	.994	.002 29	15.2	41.6	.000000	.000 299	.994	.002 24	15.2	42.4	.000000	.000 293	.994	.002 20	15.2	43.2	.000000	.000 288
226 800	000	.994	.002 81	19.2	42.7	.000 000	.000 292	.994	.002 75	19.2	43.5	.000000	.000 286	.994	.002 70	19.2	44.3	.000000	.000 281
0 000	00	.993	.003 66	25.4	47.9	.000000	.000 286	.993	.003 59	25.4	48.8	.000000	.000 281	.993	.003 52	25.4	49.5	.000000	.000 276
000	0	.993	.004 48	31.7	48.5	.000000	.000 282	.993	.004 39	31.7	49.3	.000000	.000 276	.993	.004 33	31.7	50.0	.000000	.000 272
00	1	.993	.005 46	39.3	49.1	-.000 001	.000 277	.993	.005 36	39.3	49.9	.000000	.000 272	.993	.005 28	39.3	50.7	.000000	.000 267
0	2	.993	.006 67	48.9	49.7	-.000 001	.000 272	.993	.006 55	48.9	50.5	-.000 001	.000 267	.993	.006 44	48.9	51.3	-.000001	.000 262
1	3	.993	.008 23	61.3	50.4	-.000 001	.000 267	.993	.008 08	61.3	51.2	-.000 001	.000 262	.993	.007 96	61.3	52.0	-.000 001	.000 259
2	4	.993	.010 2	77.2	51.1	-.000 001	.000 263	.993	.010 0	77.2	51.9	-.000 001	.000 259	.993	.009 85	77.2	52.6	-.000001	.000 254
3	5	.993	.012 7	97.5	51.8	-.000 001	.000 259	.993	.012 4	97.5	52.6	-.000 001	.000 254	.993	.012 3	97.5	53.4	-.000001	.000 250
4	6	.993	.015 7	123.	52.6	-.000 001	.000 255	.993	.015 4	123.	53.4	-.000001	.000 250	.993	.015 2	123.	54.2	-.000001	.000 246

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} +\right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} +\right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} +\right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XXXIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

60 MILES—96.56 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

3 FEET— .914 METER

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.001 30	5.58	33.5	.000 000	.000 464
600 000	.992	.001 39	6.01	33.8	.000 000	.000 460
550 000	.992	.001 49	6.52	34.1	.000 000	.000 455
500 000	.992	.001 62	7.14	34.5	.000 000	.000 450
450 000	.992	.001 77	7.90	34.8	.000 000	.000 445
400 000	.992	.001 95	8.86	35.4	.000 000	.000 439
350 000	.992	.002 19	10.1	35.9	.000 000	.000 433
300 000	.992	.002 51	11.7	36.5	.000 000	.000 425
250 000	.992	.002 95	14.1	37.1	.000 000	.000 417
0 000	.992	.003 41	16.6	38.1	.000 000	.000 409
000	.992	.004 19	20.9	39.0	.000 001	.000 400
00	.992	.005 16	26.3	39.8	-.000 001	.000 391
0	.992	.006 37	33.1	40.7	-.000 001	.000 382
1	.992	.007 85	41.8	41.6	-.000 001	.000 374
2	.992	.009 69	52.6	42.5	-.000 001	.000 366
3	.992	.012 0	66.4	43.4	-.000 001	.000 358
4	.992	.014 8	83.7	44.4	-.000 002	.000 351
5	.992	.018 3	106.	45.5	-.000 002	.000 345
6	.992	.022 6	133.	46.7	-.000 003	.000 337

5 FEET—1.524 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.001 16	5.58	37.2	.000 000	.000 415
600 000	.992	.001 24	6.01	37.5	.000 000	.000 412
550 000	.992	.001 34	6.52	37.8	.000 000	.000 408
500 000	.992	.001 45	7.14	38.2	.000 000	.000 404
450 000	.992	.001 59	7.90	38.5	.000 000	.000 400
400 000	.992	001 76	8.86	39.2	.000 000	.000 395
350 000	.992	.001 98	10.1	39.6	.000 000	.000 390
300 000	.992	.002 27	11.7	40.2	.000 000	.000 384
250 000	.992	.002 67	14.1	40.8	.000 000	.000 378
0 000	.992	.003 09	16.6	41.9	.000 000	.000 371
000	.992	.003 81	20.9	42.7	.000 000	.000 363
00	.992	.004 70	26.3	43.5	-.000 001	.000 355
0	.992	.005 81	33.1	44.4	-.000 001	.000 349
1	.992	.007 17	41.8	45.3	-.000 001	.000 342
2	.992	.008 87	52.6	46.2	-.000 001	.000 335
3	.992	.011 0	66.4	47.1	-.000 001	.000 329
4	.992	.013 6	83.7	48.1	-.000 001	.000 323
5	.992	.016 8	106.	49.1	-.000 002	.000 317
6	.992	.020 8	133.	50.3	-.000 002	.000 311

7 FEET—2 134 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.001 09	5.58	39.6	.000 000	.000 388
600 000	.992	.001 16	6.01	40.0	.000 000	.000 385
550 000	.992	001 25	6.52	40.3	.000 000	.000 382
500 000	.992	.001 36	7.14	40.6	.000 000	.000 378
450 000	.992	.001 49	7.90	41.0	.000 000	.000 375
400 000	.992	001 65	8.86	41.5	.000 000	.000 370
350 000	.992	.001 86	10.1	42.0	.000 000	.000 366
300 000	.992	.002 13	11.7	42.6	.000 000	.000 361
250 000	.992	.002 51	14.1	43.3	.000 000	.000 355
0 000	.992	002 91	16.6	44.3	.000 000	.000 349
000	.992	.003 59	20.9	45.2	.000 000	.000 342
00	.992	004 44	26.3	46.0	.000 000	.000 336
0	.992	.005 49	33.1	46.9	-.000 001	.000 330
1	.992	.006 78	41.8	47.7	-.000 001	.000 323
2	.992	.008 39	52.6	48.6	-.000 001	.000 317
3	.992	.010 4	66.4	49.5	-.000 001	.000 312
4	.992	.012 9	83.7	50.5	-.000 001	.000 306
5	.992	.016 0	106.	51.5	-.000 002	.000 301
6	.992	.019 8	133.	52.7	-.000 002	.000 296

9 FEET—2.743 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.001 04	5.58	41.5	.000 000	.000 370
600 000	.992	.001 11	6.01	41.8	.000 000	.000 367
550 000	.992	.001 20	6.52	42.1	.000 000	.000 364
500 000	.992	.001 30	7.14	42.4	.000 000	.000 361
450 000	.992	.001 42	7.90	42.9	.000 000	.000 358
400 000	.992	.001 58	8.86	43.4	.000 000	.000 354
350 000	.992	.001 78	10.1	43.9	.000 000	.000 350
300 000	.992	.002 04	11.7	44.4	.000 000	.000 345
250 000	.992	.002 40	14.1	45.1	.000 000	.000 340
0 000	.992	.002 79	16.6	46.1	.000 000	.000 335
000	.992	.003 45	20.9	46.9	.000 000	.000 329
00	.992	.004 26	26.3	47.8	.000 000	.000 323
0	.992	.005 27	33.1	48.7	-.000 001	.000 317
1	.992	.006 52	41.8	49.5	-.000 001	.000 311
2	.992	.008 08	52.6	50.5	-.000 001	.000 305
3	.992	.010 0	66.4	51.4	-.000 001	.000 300
4	.992	.012 4	83.7	52.4	-.000 001	.000 295
5	.992	015 4	106.	53.4	-.000 001	.000 290
6	.992	.019 1	133.	54.5	-.000 002	.000 285

11 FEET—3.353 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.001 00	5.58	42.9	.000 000	.000 357
600 000	.992	.001 07	6.01	43.3	.000 000	.000 354
550 000	.992	.001 15	6.52	43.6	.000 000	.000 352
500 000	.992	.001 25	7.14	43.9	.000 000	.000 349
450 000	.992	.001 37	7.90	44.3	.000 000	.000 346
400 000	.992	.001 52	8.86	44.8	.000 000	.000 342
350 000	.992	.001 72	10.1	45.3	.000 000	.000 338
300 000	.992	.001 97	11.7	45.9	.000 000	.000 334
250 000	.992	.002 33	14.1	46.6	.000 000	.000 329
0 000	.992	.002 70	16.6	47.6	.000 000	.000 324
000	.992	.003 33	20.9	48.4	.000 000	.000 318
00	.992	.004 13	26.3	49.3	.000 000	.000 312
0	.992	.005 11	33.1	50.2	-.000 001	.000 307
1	.992	.006 33	41.8	51.0	-.000 001	.000 302
2	.992	.007 84	52.6	51.9	-.000 001	.000 296
3	.992	.009 73	66.4	52.8	-.000 001	.000 291
4	.992	.012 1	83.7	53.8	-.000 001	.000 287
5	.992	.015 0	106.	54.8	-.000 001	.000 282
6	.992	.018 6	133.	55.9	-.000 002	.000 278

13 FEET—3.962 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.000 972	5.58	44.1	.000 000	.000 346
600 000	.992	.001 04	6.01	44.5	.000 000	.000 344
550 000	.992	.001 12	6.52	44.8	.000 000	.000 342
500 000	.992	.001 22	7.14	45.1	.000 000	.000 339
450 000	.992	.001 34	7.90	45.5	.000 000	.000 336
400 000	.992	.001 48	8.86	46.0	.000 000	.000 333
350 000	.992	.001 67	10.1	46.6	.000 000	.000 329
300 000	.992	.001 92	11.7	47.1	.000 000	.000 325
250 000	.992	.002 26	14.1	47.8	.000 000	.000 320
0 000	.992	.002 63	16.6	48.8	.000 000	.000 315
000	.992	.003 25	20.9	49.6	.000 000	.000 310
00	.992	.004 02	26.3	50.5	.000 000	.000 305
0	.992	.004 98	33.1	51.3	-.000 000	.000 299
1	.992	.006 18	41.8	52.2	-.000 001	.000 294
2	.992	.007 65	52.6	53.1	-.000 001	.000 289
3	.992	.009 49	66.4	54.0	-.000 001	.000 284
4	.992	.011 8	83.7	55.0	-.000 001	.000 280
5	.992	.014 6	106.	56.0	-.000 001	.000 275
6	.992	.018 1	133.	57.1	-.000 002	.000 271

15 FEET—4.572 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.000 950	5.58	45.2	.000 000	.000 339
600 000	.992	.001 02	6.01	45.5	.000 000	.000 336
550 000	.992	.001 10	6.52	45.8	.000 000	.000 334
500 000	.992	.001 19	7.14	46.1	.000 000	.000 331
450 000	.992	.001 31	7.90	46.6	.000 000	.000 329
400 000	.992	.001 45	8.86	47.1	.000 000	.000 325
350 000	.992	.001 63	10.1	47.6	.000 000	.000 321
300 000	.992	.001 88	11.7	48.1	.000 000	.000 318
250 000	.992	.002 21	14.1	48.8	.000 000	.000 313
0 000	.992	.002 57	16.6	49.8	.000 000	.000 309
000	.992	.003 18	20.9	50.6	.000 000	.000 303
00	.992	.003 94	26.3	51.5	.000 000	.000 298
0	.992	.004 88	33.1	52.4	-.000 000	.000 293
1	.992	.006 04	41.8	53.2	-.000 001	.000 288
2	.992	.007 51	52.6	54.1	-.000 001	.000 284
3	.992	.009 31	66.4	55.1	-.000 001	.000 279
4	.992	.011 6	83.7	56.0	-.000 001	.000 275
5	.992	.014 4	106.	57.1	-.000 001	.000 270
6	.992	.017 8	133.	58.2	-.000 002	.000 266

17 FEET—5.182 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.000 930	5.58	46.1	.000 000	.000 332
600 000	.992	.000 995	6.01	46.4	.000 000	.000 329
550 000	.992	.001 07	6.52	46.7	.000 000	.000 327
500 000	.992	.001 17	7.14	47.0	.000 000	.000 324
450 000	.992	.001 28	7.90	47.5	.000 000	.000 322
400 000	.992	.001 42	8.86	48.0	.000 000	.000 318
350 000	.992	.001 60	10.1	48.5	.000 000	.000 315
300 000	.992	.001 84	11.7	49.0	.000 000	.000 311
250 000	.992	.002 17	14.1	49.7	.000 000	.000 307
0 000	.992	.002 52	16.6	50.7	.000 000	.000 303
000	.992	.003 12	20.9	51.5	.000 000	.000 297
00	.992	.003 87	26.3	52.4	.000 000	.000 293
0	.992	.004 79	33.1	53.3	.000 000	.000 288
1	.992	.005 94	41.8	54.2	-.000 001	.000 283
2	.992	.007 37	52.6	55.1	-.000 001	.000 278
3	.992	.009 15	66.4	56.0	-.000 001	.000 274
4	.992	.011 4	83.7	56.9	-.000 001	.000 270
5	.992	.014 1	106.	58.0	-.000 001	.000 266
6	.992	.017 5	133.	59.1	-.000 002	.000 262

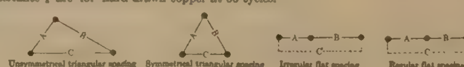
19 FEET—5.791 METERS

CIRCULAR MILS OR A. W. G (B. & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.992	.000 913	5.58	46.9	.000 000	.000 326
600 000	.992	.000 977	6.01	47.2	.000 000	.000 323
550 000	.992	.001 05	6.52	47.5	.000 000	.000 321
500 000	.992	.001 15	7.14	47.9	.000 000	.000 319
450 000	.992	.001 26	7.90	48.2	.000 000	.000 316
400 000	.992	.001 39	8.86	48.8	.000 000	.000 313
350 000	.992	.001 57	10.1	49.3	.000 000	.000 310
300 000	.992	.001 81	11.7	49.9	.000 000	.000 306
250 000	.992	.002 14	14.1	50.5	.000 000	.000 302
0 000	.992	.002 48	16.6	51.5	.000 000	.000 298
000	.992	.003 07	20.9	52.4	.000 000	.000 293
00	.992	.003 80	26.3	53.2	.000 000	.000 288
0	.992	.004 71	33.1	54.1	.000 000	.000 283
1	.992	.005 85	41.8	55.0	-.000 001	.000 279
2	.992	.007 25	52.6	55.8	-.000 001	.000 274
3	.992	.009 01	66.4	56.8	-.000 001	.000 270
4	.992	.011 2	83.7	57.7	-.000 001	.000 266
5	.992	.013 9	106.	58.7	-.000 001	.000 262
6	.992	.017 3	133.	59.8	-.000 001	.000 258

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XL—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

60 MILES—96.56 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	3 FEET— .914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.993	.001 38	5.50	29.8	.000 000	.000 497	.993	.001 22	5.50	33.5	.000 000	.000 442	.993	.001 14	5.50	36.0	.000 000	.000 411
954 000	600 000	.993	.001 47	5.95	30.1	.000 000	.000 493	.993	.001 31	5.95	33.8	.000 000	.000 438	.993	.001 22	5.95	36.3	.000 000	.000 408
874 500	550 000	.993	.001 59	6.51	30.4	.000 000	.000 487	.993	.001 42	6.51	34.1	.000 000	.000 434	.993	.001 32	6.51	36.6	.000 000	.000 405
795 000	500 000	.993	.001 72	7.10	30.8	.000 000	.000 482	.993	.001 53	7.10	34.5	.000 000	.000 429	.993	.001 43	7.10	36.9	.000 000	.000 400
715 500	450 000	.993	.001 90	7.94	31.1	.000 000	.000 476	.993	.001 69	7.94	34.8	.000 000	.000 424	.993	.001 58	7.94	37.3	.000 000	.000 396
636 000	400 000	.993	.002 10	8.90	31.6	.000 000	.000 469	.993	.001 88	8.90	35.3	.000 000	.000 420	.993	.001 75	8.90	37.7	.000 000	.000 392
556 500	350 000	.993	.002 35	10.0	31.7	.000 000	.000 467	.993	.002 10	10.0	35.4	.000 000	.000 417	.993	.001 97	10.0	37.9	.000 000	.000 390
477 000	300 000	.993	.002 70	11.7	32.3	.000 000	.000 459	.993	.002 42	11.7	36.0	.000 000	.000 411	.993	.002 26	11.7	38.4	.000 000	.000 384
397 500	250 000	.993	.003 17	14.0	33.1	.000 000	.000 449	.993	.002 85	14.0	36.8	.000 000	.000 403	.993	.002 66	14.0	39.2	.000 000	.000 378
336 400	0 000	.993	.003 68	16.6	33.7	-.000 001	.000 441	.993	.003 31	16.6	37.4	.000 000	.000 397	.993	.003 11	16.6	39.8	.000 000	.000 372
266 800	000	.993	.004 48	20.9	34.9	-.000 001	.000 426	.993	.004 04	20.9	38.6	-.000 001	.000 384	.993	.003 80	20.9	41.0	.000 000	.000 362
0 000	00	.992	.005 79	27.7	40.6	-.000 001	.000 416	.992	.005 24	27.7	44.3	-.000 001	.000 376	.992	.004 93	27.7	46.7	-.000 001	.000 354
000	0	.992	.007 06	34.6	41.2	-.000 001	.000 406	.992	.006 39	34.6	44.9	-.000 001	.000 368	.992	.006 03	34.6	47.3	-.000 001	.000 347
00	1	.992	.008 54	42.8	41.9	-.000 001	.000 397	.992	.007 77	42.8	45.6	-.000 001	.000 361	.992	.007 33	42.8	48.0	-.000 001	.000 341
0	2	.992	.010 4	53.3	42.6	-.000 001	.000 388	.992	.009 46	53.3	46.3	-.000 001	.000 353	.992	.008 94	53.3	48.7	-.000 001	.000 334
1	3	.992	.012 8	66.8	43.4	-.000 002	.000 379	.992	.011 6	66.8	47.1	-.000 001	.000 347	.992	.011 0	66.8	49.4	-.000 001	.000 327
2	4	.992	.015 7	84.1	44.1	-.000 002	.000 372	.992	.014 4	84.1	47.8	-.000 002	.000 339	.992	.013 6	84.1	50.2	-.000 001	.000 321
3	5	.992	.019 4	106.	45.0	-.000 002	.000 364	.992	.017 8	106.	48.7	-.000 002	.000 333	.992	.016 8	106.	51.1	-.000 002	.000 315
4	6	.992	.023 9	134.	46.1	-.000 003	.000 356	.992	.022 0	134.	49.7	-.000 002	.000 327	.992	.020 8	134.	52.0	-.000 002	.000 310

		9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.993	.001 08	5.50	37.8	.000 000	.000 391	.993	.001 04	5.50	39.3	.000 000	.000 377	.993	.001 01	5.50	40.5	.000 000	.000 365
954 000	600 000	.993	.001 16	5.95	38.1	.000 000	.000 388	.993	.001 12	5.95	39.6	.000 000	.000 374	.993	.001 09	5.95	40.8	.000 000	.000 363
874 500	550 000	.993	.001 26	6.51	38.4	.000 000	.000 385	.993	.001 21	6.51	39.9	.000 000	.000 371	.993	.001 18	6.51	41.1	.000 000	.000 360
795 000	500 000	.993	.001 36	7.10	38.7	.000 000	.000 382	.993	.001 31	7.10	40.2	.000 000	.000 368	.993	.001 27	7.10	41.4	.000 000	.000 357
715 500	450 000	.993	.001 51	7.94	39.1	.000 000	.000 378	.993	.001 46	7.94	40.6	.000 000	.000 365	.993	.001 41	7.94	41.8	.000 000	.000 353
636 000	400 000	.993	.001 67	8.90	39.6	.000 000	.000 374	.993	.001 61	8.90	41.0	.000 000	.000 360	.993	.001 56	8.90	42.2	.000 000	.000 350
556 500	350 000	.993	.001 88	10.0	39.8	.000 000	.000 372	.993	.001 81	10.0	41.2	.000 000	.000 359	.993	.001 76	10.0	42.4	.000 000	.000 348
477 000	300 000	.993	.002 16	11.7	40.3	.000 000	.000 367	.993	.002 08	11.7	41.8	.000 000	.000 354	.993	.002 02	11.7	43.0	.000 000	.000 344
397 500	250 000	.993	.002 55	14.0	41.0	.000 000	.000 361	.993	.002 46	14.0	42.5	.000 000	.000 348	.993	.002 39	14.0	43.7	.000 000	.000 339
336 400	0 000	.993	.002 97	16.6	41.7	.000 000	.000 356	.993	.002 87	16.6	43.1	.000 000	.000 344	.993	.002 79	16.6	44.3	.000 000	.000 334
266 800	000	.993	.003 63	20.9	42.8	.000 000	.000 346	.993	.003 51	20.9	44.3	000 000	.000 334	.993	.003 42	20.9	45.5	.000 000	.000 326
0000	00	.992	.004 72	27.7	48.5	-.000 001	.000 339	.992	.004 57	27.7	50.0	-.000 001	.000 328	.992	.004 45	27.7	51.2	-.000 001	.000 320
000	0	.992	.005 78	34.6	49.1	-.000 001	.000 333	.992	.005 59	34.6	50.6	-.000 001	.000 322	.992	.005 45	34.6	51.8	-.000 001	.000 314
00	1	.992	.007 04	42.8	49.8	-.000 001	.000 327	.992	.006 81	42.8	51.3	-.000 001	.000 316	.992	.006 64	42.8	52.5	-.000 001	.000 308
0	2	.992	.008 58	53.3	50.5	-.000 001	.000 320	.992	.008 32	53.3	52.0	-.000 001	.000 311	.992	.008 11	53.3	53.2	- 000 001	.000 303
1	3	.992	.010 6	66.8	51.3	-.000 001	.000 315	.992	.010 3	66.8	52.7	-.000 001	.000 305	.992	.009 99	66.8	54.0	-.000 001	.000 297
2	4	.992	.013 1	84.1	52.0	-.000 001	.000 309	.992	.012 7	84.1	53.5	-.000 001	.000 300	.992	.012 4	84.1	54.7	-.000 001	.000 293
3	5	.992	.016 2	106.	52.9	-.000 002	.000 303	.992	.015 7	106.	54.3	-.000 002	.000 294	.992	.015 4	106.	55.5	-.000 001	.000 288
4	6	.992	.020 1	134.	53.9	-.000 002	.000 299	.992	.019 5	134.	55.3	-.000 002	.000 290	.992	.019 0	134.	56.5	-.000 002	.000 283

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.993	.000 985	5.50	41.5	.000 000	.000 356	.993	.000 964	5.50	42.4	.000 000	.000 348	.993	.000 946	5.50	43.2	.000 000	.000 342
954 000	600 000	.993	.001 06	5.95	41.8	.000 000	.000 354	.993	.001 04	5.95	42.7	.000 000	.000 346	.993	.001 02	5.95	43.5	.000 000	.000 339
874 500	550 000	.993	.001 15	6.51	42.1	.000 000	.000 351	.993	.001 12	6.51	43.0	.000 000	.000 344	.993	.001 10	6.51	43.8	.000 000	.000 337
795 000	500 000	.993	.001 24	7.10	42.4	.000 000	.000 348	.993	.001 22	7.10	43.3	.000 000	.000 341	.993	.001 20	7.10	44.2	.000 000	.000 335
715 500	450 000	.993	.001 38	7.94	42.9	.000 000	.000 345	.993	.001 35	7.94	43.8	.000 000	.000 338	.993	.001 32	7.94	44.5	.000 000	.000 332
636 000	400 000	.993	.001 53	8.90	43.3	.000 000	.000 341	.993	.001 50	8.90	44.2	.000 000	.000 335	.993	.001 47	8.90	45.0	.000 000	.000 329
556 500	350 000	.993	.001 71	10.0	43.5	.000 000	.000 340	.993	.001 68	10.0	44.4	.000 000	.000 333	.993	.001 65	10.0	45.1	.000 000	.000 327
477 000	300 000	.993	.001 98	11.7	44.0	.000 000	.000 336	.993	.001 93	11.7	44.9	.000 000	.000 329	.993	.001 90	11.7	45.7	.000 000	.000 323
397 500	250 000	.993	.002 33	14.0	44.7	.000 000	.000 330	.993	.002 28	14.0	45.6	.000 000	.000 324	.993	.002 25	14.0	46.5	.000 000	.000 318
336 400	0 000	.993	.002 72	16.6	45.4	.000 000	.000 326	.993	.002 67	16.6	46.3	.000 000	.000 320	.993	.002 62	16.6	47.1	.000 000	.000 314
266 800	000	.993	.003 34	20.9	46.5	.000 000	.000 318	.993	.003 28	20.9	47.4	.000 000	.000 312	.993	.003 22	20.9	48.3	.000 000	.000 306
0 000	00	.992	.004 35	27.7	52.2	.000 000	.000 312	.992	.004 27	27.7	53.2	.000 000	.000 306	.992	.004 19	27.7	54.0	.000 000	.000 301
000	0	.992	.005 33	34.6	52.9	-.000 001	.000 307	.992	.005 23	34.6	53.8	-.000 001	.000 301	.992	.005 14	34.6	54.6	-.000 001	.000 296
00	1	.992	.006 50	42.8	53.5	-.000 001	.000 302	.992	.006 38	42.8	54.4	-.000 001	.000 296	.992	.006 28	42.8	55.3	-.000 001	.000 291
0	2	.992	.007 93	53.3	54.2	-.000 001	.000 296	.992	.007 79	53.3	55.1	-.000 001	.000 291	.992	.007 66	53.3	55.9	-.000 001	.000 286
1	3	.992	.009 79	66.8	55.0	-.000 001	.000 291	.992	.009 61	66.8	55.9	-.000 001	.000 286	.992	.009 47	66.8	56.7	-.000 001	.000 282
2	4	.992	.012 1	84.1	55.8	-.000 001	.000 287	.992	.011 9	84.1	56.7	-.000 001	.000 282	.992	.011 7	84.1	57.4	-.000 001	.000 277
3	5	.992	.015 1	106.	56.6	-.000 001	.000 282	.992	.014 8	106.	57.4	-.000 001	.000 277	.992	.014 6	106.	58.3	-.000 001	.000 273
4	6	.992	.018 7	134.	57.5	-.000 002	.000 278	.992	.018 3	134.	58.4	-.000 002	.000 273	.992	.018 1	134.	59.2	-.000 002	.000 269

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XLI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

65 MILES—104.61 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

3 FEET— .914 METER

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 53	6.03	36.2	.000 000	.000 502
600 000	.991	.001 63	6.50	36.6	.000 000	.000 498
550 000	.991	.001 75	7.06	36.9	.000 000	.000 492
500 000	.991	.001 90	7.73	37.3	.000 000	.000 487
450 000	.991	.002 07	8.55	37.7	.000 000	.000 481
400 000	.991	.002 29	9.59	38.4	000 000	.000 475
350 000	.991	.002 58	10.9	38.9	.000 000	.000 468
300 000	.991	.002 95	12.7	39.5	.000 000	.000 461
250 000	.991	.003 46	15.2	40.2	-.000 001	.000 452
0 000	.991	.004 00	17.9	41.3	-.000 001	.000 443
000	.991	.004 92	22.6	42.2	-.000 001	.000 433
00	.991	.006 06	28.4	43.2	-.000 001	.000 423
0	.991	.007 47	35.8	44.1	-.000 001	.000 414
1	.991	.009 22	45.2	45.0	-.000 001	.000 405
2	.991	.011 4	57.0	46.0	-.000 002	.000 397
3	.991	.014 0	71.8	47.1	-.000 002	.000 388
4	.991	.017 3	90.6	48.2	-.000 002	.000 380
5	.991	.021 5	114.	49.4	-.000 003	.000 373
6	.991	.026 5	144.	50.7	-.000 003	.000 365

5 FEET—1.524 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 36	6.03	40.2	.000 000	.000 449
600 000	.991	.001 46	6.50	40.6	.000 000	.000 446
550 000	.991	.001 57	7.06	41.0	.000 000	.000 441
500 000	.991	.001 70	7.73	41.3	.000 000	.000 437
450 000	.991	.001 86	8.55	41.7	.000 000	.000 433
400 000	.991	.002 06	9.59	42.4	.000 000	.000 428
350 000	.991	.002 32	10.9	42.9	.000 000	.000 422
300 000	.991	.002 66	12.7	43.5	.000 000	.000 416
250 000	.991	.003 13	15.2	44.2	.000 000	.000 409
0 000	.991	.003 63	17.9	45.3	.000 000	.000 402
000	.991	.004 47	22.6	46.2	-.000 001	.000 393
00	.991	.005 51	28.4	47.2	-.000 001	.000 385
0	.991	.006 82	35.8	48.1	-.000 001	.000 378
1	.991	.008 42	45.2	49.1	-.000 001	.000 370
2	.991	.010 4	57.0	50.0	-.000 001	.000 363
3	.991	.012 9	71.8	51.0	-.000 002	.000 356
4	.991	.015 9	90.6	52.1	-.000 002	.000 349
5	.991	.019 7	114.	53.3	-.000 002	.000 343
6	.991	.024 4	144.	54.6	-.000 003	.000 337

7 FEET—2.134 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 28	6.03	42.9	.000 000	.000 420
600 000	.991	.001 36	6.50	43.3	.000 000	.000 417
550 000	.991	.001 47	7.06	43.6	.000 000	.000 413
500 000	.991	.001 59	7.73	44.0	.000 000	.000 409
450 000	.991	.001 75	8.55	44.4	.000 000	.000 406
400 000	.991	.001 94	9.59	45.0	.000 000	.000 401
350 000	.991	.002 18	10.9	45.5	.000 000	.000 397
300 000	.991	.002 50	12.7	46.1	.000 000	.000 391
250 000	.991	.002 94	15.2	46.9	.000 000	.000 384
0 000	.991	.003 42	17.9	48.0	.000 000	.000 378
000	.991	.004 21	22.6	48.9	-.000 001	.000 371
00	.991	.005 21	28.4	49.8	-.000 001	.000 363
0	.991	.006 44	35.8	50.8	-.000 001	.000 357
1	.991	.007 96	45.2	51.7	-.000 001	.000 350
2	.991	.009 85	57.0	52.7	-.000 001	.000 343
3	.991	.012 2	71.8	53.7	-.000 001	.000 338
4	.991	.015 1	90.6	54.8	-.000 002	.000 332
5	.991	.018 7	114.	55.9	-.000 002	.000 326
6	.991	.023 2	144.	57.2	-.000 002	.000 320

9 FEET—2.743 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 22	6.03	44.9	.000 000	.000 401
600 000	.991	.001 30	6.50	45.2	.000 000	.000 398
550 000	.991	.001 40	7.06	45.6	.000 000	.000 395
500 000	.991	.001 52	7.73	45.9	.000 000	.000 391
450 000	.991	.001 67	8.55	46.4	.000 000	.000 387
400 000	.991	.001 85	9.59	47.0	.000 000	.000 384
350 000	.991	.002 08	10.9	47.5	.000 000	.000 379
300 000	.991	.002 39	12.7	48.1	.000 000	.000 374
250 000	.991	.002 82	15.2	48.8	.000 000	.000 368
0 000	.991	.003 27	17.9	49.9	.000 000	.000 362
000	.991	.004 05	22.6	50.8	.000 000	.000 356
00	.991	.005 00	28.4	51.8	-.000 001	.000 349
0	.991	.006 19	35.8	52.7	-.000 001	.000 343
1	.991	.007 65	45.2	53.6	-.000 001	.000 336
2	.991	.009 48	57.0	54.7	-.000 001	.000 330
3	.991	.011 7	71.8	55.7	-.000 001	.000 325
4	.991	.014 6	90.6	56.7	-.000 002	.000 319
5	.991	.018 1	114.	57.9	-.000 002	.000 314
6	.991	.022 4	144.	59.2	-.000 002	.000 309

11 FEET—3.353 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 18	6.03	46.5	.000 000	.000 387
600 000	.991	.001 26	6.50	46.8	.000 000	.000 384
550 000	.991	.001 35	7.06	47.2	.000 000	.000 381
500 000	.991	.001 47	7.73	47.6	.000 000	.000 378
450 000	.991	.001 61	8.55	47.9	.000 000	.000 374
400 000	.991	.001 79	9.59	48.5	.000 000	.000 371
350 000	.991	.002 01	10.9	49.1	.000 000	.000 366
300 000	.991	.002 31	12.7	49.7	.000 000	.000 362
250 000	.991	.002 73	15.2	50.4	.000 000	.000 356
0 000	.991	.003 17	17.9	51.5	.000 000	.000 351
000	.991	.003 91	22.6	52.5	.000 000	.000 344
00	.991	.004 84	28.4	53.4	-.000 001	.000 338
0	.991	.006 00	35.8	54.3	-.000 001	.000 332
1	.991	.007 43	45.2	55.3	-.000 001	.000 327
2	.991	.009 20	57.0	56.2	-.000 001	.000 321
3	.991	.011 4	71.8	57.2	-.000 001	.000 316
4	.991	.014 2	90.6	58.3	-.000 001	.000 310
5	.991	.017 6	114.	59.4	-.000 002	.000 305
6	.991	.021 8	144.	60.7	-.000 002	.000 301

13 FEET—3.962 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 14	6.03	47.8	.000 000	.000 375
600 000	.991	.001 22	6.50	48.1	.000 000	.000 373
550 000	.991	.001 32	7.06	48.5	.000 000	.000 370
500 000	.991	.001 43	7.73	48.9	.000 000	.000 367
450 000	.991	.001 57	8.55	49.2	.000 000	.000 364
400 000	.991	.001 74	9.59	49.8	.000 000	.000 360
350 000	.991	.001 96	10.9	50.4	.000 000	.000 356
300 000	.991	.002 25	12.7	51.0	.000 000	.000 352
250 000	.991	.002 65	15.2	51.7	.000 000	.000 347
0 000	.991	.003 08	17.9	52.8	.000 000	.000 341
000	.991	.003 82	22.6	53.7	.000 000	.000 336
00	.991	.004 72	28.4	54.7	-.000 001	.000 330
0	.991	.005 85	35.8	55.6	-.000 001	.000 324
1	.991	.007 26	45.2	56.5	-.000 001	.000 319
2	.991	.008 98	57.0	57.5	-.000 001	.000 313
3	.991	.011 1	71.8	58.5	-.000 001	.000 308
4	.991	.013 8	90.6	59.6	-.000 001	.000 303
5	.991	.017 1	114.	60.7	-.000 002	.000 298
6	.991	.021 3	144.	62.0	-.000 002	.000 293

15 FEET—4.572 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 11	6.03	48.9	.000 000	.000 367
600 000	.991	.001 19	6.50	49.2	.000 000	.000 364
550 000	.991	.001 29	7.06	49.6	.000 000	.000 362
500 000	.991	.001 40	7.73	50.0	.000 000	.000 358
450 000	.991	.001 53	8.55	50.4	.000 000	.000 356
400 000	.991	.001 70	9.59	51.0	.000 000	.000 352
350 000	.991	.001 91	10.9	51.5	.000 000	.000 348
300 000	.991	.002 20	12.7	52.1	.000 000	.000 344
250 000	.991	.002 59	15.2	52.8	.000 000	.000 339
0 000	.991	.003 02	17.9	53.9	.000 000	.000 334
000	.991	.003 74	22.6	54.8	.000 000	.000 328
00	.991	.004 62	28.4	55.8	.000 000	.000 323
0	.991	.005 73	35.8	56.7	-.000 001	.000 317
1	.991	.007 09	45.2	57.6	-.000 001	.000 312
2	.991	.008 81	57.0	58.6	-.000 001	.000 307
3	.991	.010 9	71.8	59.7	-.000 001	.000 302
4	.991	.013 6	90.6	60.7	-.000 001	.000 297
5	.991	.016 8	114.	61.9	-.000 002	.000 293
6	.991	.020 9	144.	63.1	-.000 002	.000 288

17 FEET—5.182 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 09	6.03	49.9	.000 000	.000 359
600 000	.991	.001 17	6.50	50.2	.000 000	.000 356
550 000	.991	.001 26	7.06	50.6	.000 000	.000 354
500 000	.991	.001 37	7.73	50.9	.000 000	.000 351
450 000	.991	.001 50	8.55	51.4	.000 000	.000 349
400 000	.991	.001 66	9.59	52.0	.000 000	.000 345
350 000	.991	.001 88	10.9	52.5	.000 000	.000 341
300 000	.991	.002 15	12.7	53.1	.000 000	.000 337
250 000	.991	.002 55	15.2	53.9	.000 000	.000 332
0 000	.991	.002 96	17.9	54.9	.000 000	.000 328
000	.991	.003 66	22.6	55.8	.000 000	.000 322
00	.991	.004 54	28.4	56.7	.000 000	.000 317
0	.991	.005 63	35.8	57.7	-.000 001	.000 312
1	.991	.006 98	45.2	58.7	-.000 001	.000 306
2	.991	.008 64	57.0	59.6	-.000 001	.000 301
3	.991	.010 7	71.8	60.6	-.000 001	.000 297
4	.991	.013 3	90.6	61.7	-.000 001	.000 292
5	.991	.016 5	114.	62.8	-.000 002	.000 288
6	.991	.020 5	144.	64.1	-.000 002	.000 283

19 FEET—5.791 METERS

CIRCULAR MILS OR A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
650 000	.991	.001 07	6.03	50.7	.000 000	.000 352
600 000	.991	.001 15	6.50	51.1	.000 000	.000 350
550 000	.991	.001 24	7.06	51.4	.000 000	.000 348
500 000	.991	.001 34	7.73	51.8	.000 000	.000 345
450 000	.991	.001 47	8.55	52.2	.000 000	.000 342
400 000	.991	.001 64	9.59	52.9	.000 000	.000 339
350 000	.991	.001 85	10.9	53.4	.000 000	.000 336
300 000	.991	.002 12	12.7	54.0	.000 000	.000 332
250 000	.991	.002 51	15.2	54.7	.000 000	.000 327
0 000	.991	.002 91	17.9	55.8	.000 000	.000 323
000	.991	.003 60	22.6	56.7	.000 000	.000 317
00	.991	.004 46	28.4	57.6	.000 000	.000 312
0	.991	.005 53	35.8	58.6	-.000 001	.000 306
1	.991	.006 87	45.2	59.5	-.000 001	.000 302
2	.991	.008 51	57.0	60.5	-.000 001	.000 297
3	.991	.010 6	71.8	61.5	-.000 001	.000 292
4	.991	.013 1	90.6	62.5	-.000 001	.000 288
5	.991	.016 3	114.	63.7	-.000 002	.000 284
6	.991	.020 3	144.	64.9	-.000 002	.000 279

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

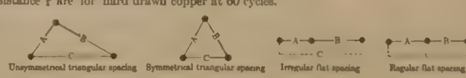


TABLE XLII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

65 MILES—104.61 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G BASED UPON COPPER 97% ALUMIN 61%	3 FEET— .914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.991	.001 61	5.96	32.3	.000 000	.000 539	.991	.001 43	5.96	36.3	.000 000	.000 478	.991	.001 33	5.96	39.0	.000 000	.000 445
954 000	600 000	.991	.001 73	6.44	32.6	.000 000	.000 533	.991	.001 54	6.44	36.6	.000 000	.000 474	.991	.001 43	6.44	39.3	.000 000	.000 442
874 500	550 000	.991	.001 87	7.04	32.9	.000 000	.000 528	.991	.001 66	7.04	36.9	.000 000	.000 470	.991	.001 55	7.04	39.6	.000 000	.000 438
795 000	500 000	.991	.002 02	7.69	33.3	.000 000	.000 522	.991	.001 80	7.69	37.3	.000 000	.000 465	.991	.001 68	7.69	39.9	.000 000	.000 434
715 500	450 000	.991	.002 23	8.59	33.7	.000 000	.000 515	.991	.001 99	8.59	37.7	.000 000	.000 460	.991	.001 85	8.59	40.4	.000 000	.000 429
636 000	400 000	.991	.002 46	9.63	34.2	.000 000	.000 508	.991	.002 20	9.63	38.2	.000 000	.000 454	.991	.002 06	9.63	40.8	.000 000	.000 425
556 500	350 000	.991	.002 76	10.9	34.4	.000 000	.000 506	.991	.002 47	10.9	38.4	.000 000	.000 452	.991	.002 31	10.9	41.0	.000 000	.000 423
477 000	300 000	.991	.003 16	12.7	35.0	-.000 001	.000 496	.991	.002 83	12.7	39.0	.000 000	.000 445	.991	.002 65	12.7	41.6	.000 000	.000 416
397 500	250 000	.991	.003 71	15.2	35.8	-.000 001	.000 486	.991	.003 34	15.2	39.8	.000 000	.000 437	.991	.003 12	15.2	42.5	.000 000	.000 409
336 400	0 000	.991	.004 32	18.0	36.5	-.000 001	.000 478	.991	.003 88	18.0	40.5	-.000 001	.000 430	.991	.003 64	18.0	43.1	.000 000	.000 403
266 800	000	.991	.005 25	22.6	37.8	-.000 001	.000 461	.991	.004 73	22.6	41.8	-.000 001	.000 416	.991	.004 45	22.6	44.4	-.000 001	.000 392
0 000	00	.990	.006 79	30.0	43.9	-.000 001	.000 450	.990	.006 15	30.0	47.9	-.000 001	.000 408	.990	.005 79	30.0	50.6	-.000 001	.000 384
000	0	.990	.008 28	37.4	44.6	-.000 001	.000 440	.990	.007 50	37.4	48.6	-.000 001	.000 399	.990	.007 07	37.4	51.3	-.000 001	.000 376
00	1	.990	.0100	46.4	45.4	-.000 001	.000 430	.990	.009 12	46.4	49.4	-.000 001	.000 391	.990	.008 60	46.4	52.0	-.000 001	.000 369
0	2	.990	.0122	57.7	46.1	-.000 002	.000 420	.990	.0111	57.7	50.1	-.000 001	.000 382	.990	.0105	57.7	52.7	-.000 001	.000 362
1	3	.990	.0150	72.3	47.0	-.000 002	.000 411	.990	.0137	72.3	51.0	-.000 002	.000 375	.990	.0129	72.3	53.6	-.000 002	.000 354
2	4	.990	.0184	91.1	47.9	-.000 002	.000 402	.990	.0168	91.1	51.8	-.000 002	.000 367	.991	.0160	91.1	54.5	-.000 002	.000 348
3	5	.990	.0228	115.	48.9	-.000 003	.000 394	.990	.0209	115.	52.8	-.000 003	.000 361	.991	.0198	115.	55.4	-.000 002	.000 342
4	6	.990	.0281	145.	50.1	-.000 004	.000 386	.991	.0258	145.	54.0	-.000 003	.000 354	.991	.0244	145.	56.5	-.000 003	.000 336

		9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS.					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.991	.001 27	5.96	41.0	.000 000	.000 424	.991	.001 22	5.96	42.5	.000 000	.000 408	.991	.001 18	5.96	43.8	.000 000	.000 395
954 000	600 000	.991	.001 36	6.44	41.3	.000 000	.000 421	.991	.001 31	6.44	42.8	.000 000	.000 405	.991	.001 27	6.44	44.1	.000 000	.000 393
874 500	550 000	.991	.001 48	7.04	41.5	.000 000	.000 417	.991	.001 42	7.04	43.2	.000 000	.000 401	.991	.001 38	7.04	44.5	.000 000	.000 390
795 000	500 000	.991	.001 60	7.69	41.9	.000 000	.000 414	.991	.001 54	7.69	43.5	.000 000	.000 398	.991	.001 49	7.69	44.9	.000 000	.000 386
715 500	450 000	.991	.001 77	8.59	42.3	.000 000	.000 409	.991	.001 71	8.59	43.9	.000 000	.000 395	.991	.001 65	8.59	45.2	.000 000	.000 382
636 000	400 000	.991	.001 96	9.63	42.9	.000 000	.000 404	.991	.001 89	9.63	44.4	.000 000	.000 390	.991	.001 83	9.63	45.7	.000 000	.000 379
556 500	350 000	.991	.002 20	10.9	43.0	.000 000	.000 403	.991	.002 12	10.9	44.6	.000 000	.000 388	.991	.002 06	10.9	45.9	.000 000	.000 377
477 000	300 000	.991	.002 53	12.7	43.6	.000 000	.000 397	.991	.002 44	12.7	45.3	.000 000	.000 383	.991	.002 37	12.7	46.5	.000 000	.000 373
397 500	250 000	.991	.002 98	15.2	44.4	.000 000	.000 391	.991	.002 88	15.2	46.0	.000 000	.000 377	.991	.002 80	15.2	47.3	.000 000	.000 367
336 400	0 000	.991	.003 48	18.0	45.1	.000 000	.000 385	.991	.003 36	18.0	46.7	.000 000	.000 372	.991	.003 27	18.0	48.0	.000 000	.000 362
266 800	000	.991	.004 26	22.6	46.4	-.000 001	.000 375	.991	.004 11	22.6	47.9	.000 000	.000 362	.991	.004 01	22.6	49.3	.000 000	.000 353
0 000	00	.990	.005 54	30.0	52.5	-.000 001	.000 367	.990	.005 36	30.0	54.2	-.000 001	.000 355	.990	.005 22	30.0	55.5	-.000 001	.000 346
000	0	.990	.006 78	37.4	53.2	-.000 001	.000 360	.990	.006 56	37.4	54.8	-.000 001	.000 349	.990	.006 39	37.4	56.1	-.000 001	.000 340
00	1	.990	.008 26	46.4	54.0	-.000 001	.000 354	.990	.007 98	46.4	55.5	-.000 001	.000 342	.990	.007 79	46.4	56.9	-.000 001	.000 334
0	2	.990	.0101	57.7	54.7	-.000 001	.000 347	.991	.009 76	57.7	56.3	-.000 001	.000 336	.991	.009 52	57.7	57.6	-.000 001	.000 328
1	3	.991	.0124	72.3	55.6	-.000 001	.000 341	.991	.0120	72.3	57.1	-.000 001	.000 331	.991	.0117	72.3	58.5	-.000 001	.000 322
2	4	.991	.0153	91.1	56.4	-.000 002	.000 334	.991	.0149	91.1	58.0	-.000 002	.000 325	.991	.0145	91.1	59.3	-.000 002	.000 317
3	5	.991	.0190	115.	57.4	-.000 002	.000 329	.991	.0184	115.	58.9	-.000 002	.000 319	.991	.0180	115.	60.3	-.000 002	.000 312
4	6	.991	.0236	145.	58.5	-.000 003	.000 323	.991	.0228	145.	60.0	-.000 002	.000 314	.991	.0223	145.	61.3	-.000 002	.000 307

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.991	.001 16	5.96	45.0	.000 000	.000 386	.991	.001 13	5.96	46.0	.000 000	.000 377	.991	.001 11	5.96	46.8	.000 000	.000 370
954 000	600 000	.991	.001 24	6.44	45.3	.000 000	.000 383	.991	.001 21	6.44	46.3	.000 000	.000 375	.991	.001 19	6.44	47.1	.000 000	.000 368
874 500	550 000	.991	.001 35	7.04	45.6	.000 000	.000 380	.991	.001 32	7.04	46.6	.000 000	.000 372	.991	.001 29	7.04	47.4	.000 000	.000 365
795 000	500 000	.991	.001 46	7.69	46.0	.000 000	.000 377	.991	.001 43	7.69	46.9	.000 000	.000 369	.991	.001 40	7.69	47.8	.000 000	.000 362
715 500	450 000	.991	.001 61	8.59	46.4	.000 000	.000 373	.991	.001 58	8.59	47.4	.000 000	.000 366	.991	.001 55	8.59	48.2	.000 000	.000 359
636 000	400 000	.991	.001 79	9.63	46.9	.000 000	.000 369	.991	.001 75	9.63	47.8	.000 000	.000 362	.991	.001 72	9.63	48.7	.000 000	.000 356
556 500	350 000	.991	.002 01	10.9	47.1	.000 000	.000 368	.991	.001 97	10.9	48.0	.000 000	.000 360	.991	.001 93	10.9	48.9	.000 000	.000 354
477 000	300 000	.991	.002 32	12.7	47.7	.000 000	.000 364	.991	.002 27	12.7	48.6	.000 000	.000 356	.991	.002 23	12.7	49.5	.000 000	.000 350
397 500	250 000	.991	.002 73	15.2	48.4	.000 000	.000 358	.991	.002 68	15.2	49.4	.000 000	.000 351	.991	.002 63	15.2	50.3	.000 000	.000 345
336 400	0 000	.991	.003 19	18.0	49.2	.000 000	.000 353	.991	.003 13	18.0	50.1	.000 000	.000 346	.991	.003 08	18.0	51.0	.000 000	.000 340
266 800	000	.991	.003 92	22.6	50.4	.000 000	.000 344	.991	.003 84	22.6	51.4	.000 000	.000 338	.991	.003 77	22.6	52.3	.000 000	.000 332
0 000	00	.990	.005 10	30.0	56.6	-.000 001	.000 338	.990	.005 00	30.0	57.6	-.000 001	.000 332	.990	.004 92	30.0	58.4	-.000 001	.000 326
000	0	.990	.006 26	37.4	57.3	-.000 001	.000 332	.990	.006 13	37.4	58.3	-.000 001	.000 326	.990	.006 04	37.4	59.1	-.000 001	.000 321
00	1	.991	.007 62	46.4	58.0	-.000 001	.000 327	.991	.007 49	46.4	59.0	-.000 001	.000 321	.991	.007 37	46.4	59.9	-.000 001	.000 316
0	2	.991	.009 31	57.7	58.8	-.000 001	.000 321	.991	.009 14	57.7	59.7	-.000 001	.000 315	.991	.008 99	57.7	60.6	-.000 001	.000 310
1	3	.991	.0115	72.3	59.6	-.000 001	.000 316	.991	.0113	72.3	60.5	-.000 001	.000 310	.991	.0111	72.3	61.4	-.000 001	.000 305
2	4	.991	.0142	91.1	60.4	-.000 001	.000 310	.991	.0140	91.1	61.4	-.000 001	.000 305	.991	.0138	91.1	62.2	-.000 001	.000 300
3	5	.991	.0177	115.	61.3	-.000 002	.000 305	.991	.0174	115.	62.3	-.000 002	.000 300	.991	.0171	115.	63.2	-.000 002	.000 296
4	6	.991	.0219	145.	62.4	-.000 002	.000 301	.991	.0215	145.	63.4	-.000 002	.000 296	.991	.0212	145.	64.3	-.000 002	.000 291

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing. It is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XLIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

70 MILES—112.66 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B. & S.)	3 FEET— .914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.989	.001 77	6.50	39.0	.000 000	.000 541	.989	.001 58	6.50	43.3	.000 000	.000 483	.989	.001 48	6.50	46.2	.000 000	.000 453
600 000	.989	.001 89	7.00	39.4	.000 000	.000 536	.989	.001 69	7.00	43.7	.000 000	.000 480	.989	.001 58	7.00	46.6	.000 000	.000 449
550 000	.989	.002 03	7.60	39.8	.000 000	.000 530	.989	.001 82	7.60	44.1	.000 000	.000 475	.989	.001 70	7.60	47.0	.000 000	.000 445
500 000	.989	.002 20	8.32	40.2	.000 000	.000 525	.989	.001 97	8.32	44.5	.000 000	.000 471	.989	.001 85	8.32	47.4	.000 000	.000 441
450 000	.989	.002 40	9.21	40.6	.000 000	.000 518	.989	.002 16	9.21	44.9	.000 000	.000 466	.989	.002 02	9.21	47.8	.000 000	.000 437
400 000	.989	.002 66	10.3	41.3	.000 000	.000 511	.989	.002 39	10.3	45.6	.000 000	.000 460	.989	.002 24	10.3	48.4	.000 000	.000 432
350 000	.989	.002 98	11.8	41.9	-.000 001	.000 504	.989	.002 69	11.8	46.2	.000 000	.000 454	.989	.002 52	11.8	49.0	.000 000	.000 427
300 000	.989	.003 41	13.7	42.5	-.000 001	.000 496	.989	.003 08	13.7	46.8	.000 000	.000 448	.989	.002 89	13.7	49.7	.000 000	.000 421
250 000	.989	.004 01	16.4	43.3	-.000 001	.000 486	.989	.003 62	16.4	47.6	-.000 001	.000 440	.989	.003 41	16.4	50.5	.000 000	.000 414
0 000	.989	.004 64	19.3	44.5	-.000 001	.000 477	.989	.004 20	19.3	48.8	-.000 001	.000 433	.989	.003 96	19.3	51.6	-.000 001	.000 407
000	.989	.005 70	24.3	45.5	-.000 001	.000 466	.989	.005 18	24.3	49.8	-.000 001	.000 423	.989	.004 88	24.3	52.6	-.000 001	.000 399
00	.989	.007 02	30.6	46.5	-.000 001	.000 456	.989	.006 38	30.6	50.8	-.000 001	.000 414	.989	.006 03	30.6	53.6	-.000 001	.000 391
0	.989	.008 66	38.6	47.5	-.000 001	.000 446	.989	.007 90	38.6	51.8	-.000 001	.000 407	.989	.007 46	38.6	54.6	-.000 001	.000 384
1	.989	.010 7	48.6	48.5	-.000 002	.000 436	.989	.009 75	48.6	52.8	-.000 001	.000 398	.989	.009 22	48.6	55.7	-.000 001	.000 377
2	.989	.013 2	61.3	49.6	-.000 002	.000 427	.989	.012 1	61.3	53.9	-.000 002	.000 391	.989	.011 4	61.3	56.7	-.000 001	.000 370
3	.989	.016 3	77.3	50.7	-.000 002	.000 418	.989	.014 9	77.3	55.0	-.000 002	.000 384	.989	.014 1	77.3	57.8	-.000 002	.000 363
4	.989	.020 1	97.5	[illegible]1.9	-.000 003	.000 409	.989	.018 4	97.5	56.2	-.000 002	.000 376	.989	.017 5	97.5	59.0	-.000 002	.000 357
5	.989	.024 8	123.	53.3	-.000 003	.000 402	.989	.022 8	123.	57.5	-.000 003	.000 369	.989	.021 7	123.	60.3	-.000 003	.000 351
6	.989	.030 7	155.	54.8	-.000 004	.000 393	.989	.028 3	155.	59.0	-.000 003	.000 363	.989	.026 9	155.	61.8	-.000 003	.000 345

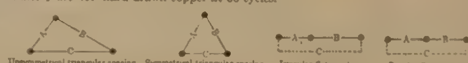
	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.989	.001 41	6.50	48.3	.000 000	.000 432	.990	.001 36	6.50	50.0	.000 000	.000 416	.990	.001 32	6.50	51.4	.000 000	.000 404
600 000	.989	.001 51	7.00	48.7	.000 000	.000 428	.990	.001 46	7.00	50.4	.000 000	.000 413	.990	.001 41	7.00	51.8	.000 000	.000 401
550 000	.989	.001 62	7.60	49.1	.000 000	.000 425	.990	.001 57	7.60	50.8	.000 000	.000 410	.990	.001 52	7.60	52.2	.000 000	.000 398
500 000	.989	.001 76	8.32	49.5	.000 000	.000 421	.990	.001 70	8.32	51.2	.000 000	.000 407	.990	.001 66	8.32	52.6	.000 000	.000 396
450 000	.989	.001 93	9.21	50.0	.000 000	.000 417	.990	.001 87	9.21	51.6	.000 000	.000 403	.990	.001 82	9.21	53.0	.000 000	.000 392
400 000	.989	.002 14	10.3	50.6	.000 000	.000 413	.990	.002 07	10.3	52.3	.000 000	.000 399	.990	.002 01	10.3	53.7	.000 000	.000 388
350 000	.989	.002 41	11.8	51.1	.000 000	.000 408	.990	.002 33	11.8	52.8	.000 000	.000 394	.990	.002 27	11.8	54.3	.000 000	.000 384
300 000	.989	.002 77	13.7	51.8	.000 000	.000 403	.990	.002 68	13.7	53.5	.000 000	.000 389	.990	.002 61	13.7	54.9	.000 000	.000 379
250 000	.989	.003 26	16.4	52.5	.000 000	.000 396	.990	.003 16	16.4	54.3	.000 000	.000 384	.990	.003 07	16.4	55.7	.000 000	.000 373
0 000	.989	.003 79	19.3	53.7	.000 000	.000 390	.989	.003 67	19.3	55.5	.000 000	.000 377	.989	.003 57	19.3	56.9	.000 000	.000 368
000	.989	.004 68	24.3	54.7	-.000 001	.000 383	.989	.004 53	24.3	56.5	-.000 001	.000 370	.989	.004 42	24.3	57.9	-.000 001	.000 361
00	.989	.005 79	30.6	55.7	-.000 001	.000 376	.989	.005 61	30.6	57.5	-.000 001	.000 364	.989	.005 47	30.6	58.9	-.000 001	.000 355
0	.989	.007 16	38.6	56.7	-.000 001	.000 369	.989	.006 95	38.6	58.5	-.000 001	.000 358	.989	.006 77	38.6	59.9	-.000 001	.000 349
1	.989	.008 86	48.6	57.8	-.000 001	.000 362	.989	.008 60	48.6	59.5	-.000 001	.000 352	.989	.008 40	48.6	60.9	-.000 001	.000 343
2	.989	.011 0	61.3	58.9	-.000 001	.000 356	.989	.010 7	61.3	60.6	-.000 001	.000 345	.989	.010 4	61.3	62.0	-.000 001	.000 337
3	.989	.013 6	77.3	60.0	-.000 002	.000 349	.989	.013 2	77.3	61.7	-.000 002	.000 340	.989	.012 9	77.3	63.0	-.000 001	.000 331
4	.989	.016 9	97.5	61.2	-.000 002	.000 344	.989	.016 4	97.5	62.8	-.000 002	.000 334	.989	.016 0	97.5	64.2	-.000 002	.000 326
5	.989	.020 9	123.	6[illegible].5	-.000 002	.000 338	.989	.020 3	123.	64.1	-.000 002	.000 329	.989	.019 9	123.	65.5	-.000 002	.000 321
6	.989	.025 9	155.	63.9	-.000 003	.000 333	.989	.025 2	155.	65.6	-.000 003	.000 324	.989	.024 7	155.	66.9	-.000 003	.000 316

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.990	.001 29	6.50	52.7	.000 000	.000 395	.990	.001 26	6.50	53.7	.000 000	.000 386	.990	.001 24	6.50	54.6	.000 000	.000 379
600 000	.990	.001 38	7.00	53.0	.000 000	.000 392	.990	.001 35	7.00	54.1	.000 000	.000 384	.990	.001 33	7.00	55.0	.000 000	.000 377
550 000	.990	.001 49	7.60	53.4	.000 000	.000 389	.990	.001 46	7.60	54.5	.000 000	.000 381	.990	.001 43	7.60	55.4	.000 000	.000 375
500 000	.990	.001 62	8.32	53.8	.000 000	.000 386	.990	.001 58	8.32	54.8	.000 000	.000 378	.990	.001 56	8.32	55.8	.000 000	.000 372
450 000	.990	.001 77	9.21	54.3	.000 000	.000 383	.990	.001 74	9.21	55.3	.000 000	.000 375	.990	.001 71	9.21	56.2	.000 000	.000 368
400 000	.990	.001 97	10.3	54.9	.000 000	.000 379	.990	.001 93	10.3	56.0	.000 000	.000 371	.990	.001 89	10.3	56.9	.000 000	.000 365
350 000	.990	.002 22	11.8	55.5	.000 000	.000 375	.990	.002 17	11.8	56.5	.000 000	.000 368	.990	.002 14	11.8	57.5	.000 000	.000 361
300 000	.990	.002 55	13.7	56.1	.000 000	.000 370	.990	.002 49	13.7	57.1	.000 000	.000 363	.990	.002 46	13.7	58.1	.000 000	.000 357
250 000	.990	.003 00	16.4	56.9	.000 000	.000 365	.990	.002 95	16.4	58.0	.000 000	.000 358	.990	.002 90	16.4	58.9	.000 000	.000 352
0 000	.989	.003 50	19.3	58.1	.000 000	.000 360	.990	.003 43	19.3	59.1	.000 000	.000 353	.990	.003 37	19.3	60.1	.000 000	.000 347
000	.989	.004 33	24.3	59.1	-.000 001	.000 354	.990	.004 24	24.3	60.1	.000 000	.000 347	.990	.004 17	24.3	61.1	.000 000	.000 341
00	.989	.005 35	30.6	60.1	-.000 001	.000 347	.990	.005 26	30.6	61.1	-.000 001	.000 341	.990	.005 17	30.6	62.1	-.000 001	.000 336
0	.989	.006 64	38.6	61.1	-.000 001	.000 342	.990	.006 52	38.6	62.2	-.000 001	.000 336	.990	.006 41	38.6	63.1	-.000 001	.000 330
1	.989	.008 21	48.6	62.1	-.000 001	.000 336	.990	.008 08	48.6	63.2	-.000 001	.000 330	.990	.007 96	48.6	64.1	-.000 001	.000 325
2	.989	.010 2	61.3	63.1	-.000 001	.000 331	.990	.010 0	61.3	64.2	-.000 001	.000 324	.990	.009 86	61.3	65.2	-.000 001	.000 320
3	.989	.012 6	77.3	64.3	-.000 001	.000 325	.990	.012 4	77.3	65.3	-.000 001	.000 320	.990	.012 2	77.3	66.2	-.000 001	.000 315
4	.989	.015 7	97.5	65.5	-.000 002	.000 320	.990	.015 4	97.5	66.5	-.000 002	.000 315	.990	.015 2	97.5	67.4	-.000 002	.000 310
5	.989	.019 5	123.	66.7	-.000 002	.000 315	.990	.019 2	123.	67.8	-.000 002	.000 310	.990	.018 9	123.	68.7	-.000 002	.000 306
6	.989	.024 2	155.	68.2	-.000 003	.000 310	.989	.023 8	155.	69.2	-.000 002	.000 305	.990	.023 5	155.	70.1	-.000 002	.000 301

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XLIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

70 MILES—112.66 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	3 FEET—.914 METER						5 FEET—1.524 METERS						7 FEET—2.134 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.990	.00187	6.41	34.7	.000000	.000580	.990	.00166	6.41	39.1	.000000	.000515	.990	.00155	6.41	41.9	.000000	.000479
954 000	600 000	.990	.00200	6.93	35.1	.000000	.000574	.990	.00178	6.93	39.4	.000000	.000510	.990	.00166	6.93	42.3	.000000	.000476
874 500	550 000	.990	.00217	7.58	35.5	.000000	.000568	.990	.00193	7.58	39.8	.000000	.000506	.990	.00180	7.58	42.6	.000000	.000472
795 000	500 000	.990	.00234	8.27	35.9	.000000	.000562	.990	.00208	8.27	40.2	.000000	.000500	.990	.00194	8.27	43.0	.000000	.000467
715 500	450 000	.990	.00258	9.25	36.3	.000000	.000555	.990	.00230	9.25	40.6	.000000	.000495	.990	.00215	9.25	43.5	.000000	.000462
636 000	400 000	.990	.00285	10.4	36.8	-.000001	.000547	.990	.00255	10.4	41.1	.000000	.000489	.990	.00238	10.4	44.0	.000000	.000457
556 500	350 000	.990	.00320	11.7	37.0	-.000001	.000544	.990	.00286	11.7	41.3	.000000	.000486	.990	.00267	11.7	44.2	.000000	.000455
477 000	300 000	.990	.00367	13.6	37.7	-.000001	.000534	.990	.00328	13.6	42.0	-.000001	.000479	.990	.00307	13.6	44.8	.000000	.000448
397 500	250 000	.990	.00431	16.3	38.5	-.000001	.000523	.990	.00387	16.3	42.9	-.000001	.000470	.990	.00362	16.3	45.7	-.000001	.000440
336 400	0 000	.990	.00500	19.3	39.3	-.000001	.000514	.990	.00450	19.3	43.6	-.000001	.000463	.990	.00422	19.3	46.4	-.000001	.000434
266 800	000	.990	.00609	24.3	40.7	-.000001	.000497	.990	.00549	24.3	45.0	-.000001	.000448	.990	.00516	24.3	47.8	-.000001	.000421
0 000	00	.988	.00787	32.2	47.3	-.000001	.000485	.989	.00713	32.2	51.6	-.000001	.000439	.989	.00671	32.2	54.5	-.000001	.000413
000	0	.989	.00960	40.2	48.0	-.000002	.000474	.989	.00869	40.2	52.4	-.000001	.000429	.989	.00820	40.2	55.2	-.000001	.000405
00	1	.989	.0116	49.9	48.9	-.000002	.000462	.989	.0106	49.9	53.2	-.000001	.000421	.989	.00997	49.9	56.0	-.000001	.000397
0	2	.989	.0141	62.1	49.7	-.000002	.000452	.989	.0129	62.1	54.0	-.000002	.000412	.989	.0122	62.1	56.8	-.000002	.000389
1	3	.989	.0173	77.8	50.7	-.000003	.000442	.989	.0158	77.8	55.0	-.000002	.000404	.989	.0150	77.8	57.7	-.000002	.000382
2	4	.989	.0214	98.0	51.6	-.000003	.000433	.989	.0195	98.0	55.9	-.000003	.000395	.989	.0185	98.0	58.7	-.000002	.000375
3	5	.989	.0264	124.	52.8	-.000004	.000424	.989	.0242	124.	57.0	-.000003	.000389	.989	.0229	124.	59.8	-.000003	.000368
4	6	.989	.0325	156.	54.2	-.000005	.000415	.989	.0299	156.	58.3	-.000004	.000381	.989	.0283	156.	61.1	-.000003	.000361

		9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.990	.00147	6.41	44.1	.000000	.000456	.990	.00142	6.41	45.8	.000000	.000439	.990	.00137	6.41	47.2	.000000	.000426
954 000	600 000	.990	.00158	6.93	44.4	.000000	.000453	.990	.00152	6.93	46.1	.000000	.000436	.990	.00148	6.93	47.5	.000000	.000423
874 500	550 000	.990	.00171	7.58	44.7	.000000	.000449	.990	.00165	7.58	46.5	.000000	.000432	.990	.00160	7.58	47.9	.000000	.000419
795 000	500 000	.990	.00185	8.27	45.1	.000000	.000445	.990	.00178	8.27	46.8	.000000	.000428	.990	.00173	8.27	48.3	.000000	.000416
715 500	450 000	.990	.00205	9.25	45.6	.000000	.000440	.990	.00198	9.25	47.3	.000000	.000425	.990	.00192	9.25	48.7	.000000	.000412
636 000	400 000	.990	.00227	10.4	46.1	.000000	.000435	.990	.00219	10.4	47.8	.000000	.000420	.990	.00213	10.4	49.2	.000000	.000407
556 500	350 000	.990	.00255	11.7	46.3	.000000	.000434	.990	.00246	11.7	48.0	.000000	.000418	.990	.00239	11.7	49.4	.000000	.000406
477 000	300 000	.990	.00293	13.6	47.0	.000000	.000428	.990	.00283	13.6	48.7	.000000	.000412	.990	.00275	13.6	50.1	.000000	.000401
397 500	250 000	.990	.00346	16.3	47.8	.000000	.000421	.990	.00334	16.3	49.6	.000000	.000406	.990	.00325	16.3	50.9	.000000	.000395
336 400	0 000	.990	.00403	19.3	48.6	-.000001	.000414	.990	.00390	19.3	50.3	-.000001	.000400	.990	.00379	19.3	51.6	.000000	.000389
266 800	000	.990	.00494	24.3	49.9	-.000001	.000403	.990	.00477	24.3	51.6	-.000001	.000389	.990	.00465	24.3	53.1	-.000001	.000380
0 000	00	.989	.00642	32.2	56.6	-.000001	.000395	.989	.00621	32.2	58.3	-.000001	.000382	.989	.00605	32.2	59.7	-.000001	.000372
000	0	.989	.00786	40.2	57.3	-.000001	.000388	.989	.00760	40.2	59.0	-.000001	.000375	.989	.00741	40.2	60.4	-.000001	.000365
00	1	.989	.00957	49.9	58.1	-.000001	.000381	.989	.00925	49.9	59.8	-.000001	.000368	.989	.00903	49.9	61.2	-.000001	.000359
0	2	.989	.0117	62.1	59.0	-.000001	.000373	.989	.0113	62.1	60.6	-.000001	.000362	.989	.0110	62.1	62.0	-.000001	.000353
1	3	.989	.0144	77.8	59.9	-.000002	.000367	.989	.0139	77.8	61.5	-.000002	.000356	.989	.0136	77.8	63.0	-.000002	.000347
2	4	.989	.0178	98.0	60.8	-.000002	.000360	.989	.0172	98.0	62.5	-.000002	.000349	.989	.0168	98.0	63.9	-.000002	.000341
3	5	.989	.0220	124.	61.9	-.000003	.000354	.989	.0214	124.	63.5	-.000002	.000343	.989	.0209	124.	65.0	-.000002	.000336
4	6	.989	.0273	156.	63.2	-.000003	.000348	.989	.0265	156.	64.8	-.000003	.000338	.989	.0259	156.	66.2	-.000003	.000330

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 033 500	650 000	.990	.00134	6.41	48.4	.000000	.000415	.990	.00131	6.41	49.5	.000000	.000406	.990	.00129	6.41	50.4	.000000	.000398
954 000	600 000	.990	.00144	6.93	48.8	.000000	.000412	.990	.00141	6.93	49.8	.000000	.000403	.990	.00138	6.93	50.7	.000000	.000396
874 500	550 000	.990	.00156	7.58	49.0	.000000	.000409	.990	.00153	7.58	50.2	.000000	.000400	.990	.00150	7.58	51.1	.000000	.000393
795 000	500 000	.990	.00169	8.27	49.5	.000000	.000405	.990	.00165	8.27	50.5	.000000	.000397	.990	.00162	8.27	51.5	.000000	.000390
715 500	450 000	.990	.00187	9.25	50.0	.000000	.000402	.990	.00183	9.25	51.0	.000000	.000393	.990	.00180	9.25	51.9	.000000	.000387
636 000	400 000	.990	.00207	10.4	50.5	.000000	.000398	.990	.00203	10.4	51.5	.000000	.000390	.990	.00200	10.4	52.4	.000000	.000383
556 500	350 000	.990	.00233	11.7	50.7	.000000	.000396	.990	.00228	11.7	51.7	.000000	.000388	.990	.00224	11.7	52.6	.000000	.000381
477 000	300 000	.990	.00269	13.6	51.3	.000000	.000391	.990	.00263	13.6	52.3	.000000	.000383	.990	.00258	13.6	53.3	.000000	.000377
397 500	250 000	.990	.00317	16.3	52.1	.000000	.000385	.990	.00310	16.3	53.2	.000000	.000377	.990	.00305	16.3	54.2	.000000	.000371
336 400	0 000	.990	.00370	19.3	52.9	.000000	.000380	.990	.00363	19.3	53.9	.000000	.000373	.990	.00357	19.3	54.9	.000000	.000366
266 800	000	.990	.00454	24.3	54.2	-.000001	.000370	.990	.00445	24.3	55.3	-.000001	.000363	.990	.00438	24.3	56.3	-.000001	.000357
0 000	00	.989	.00591	32.2	60.9	-.000001	.000364	.989	.00580	32.2	62.0	-.000001	.000357	.989	.00570	32.2	62.9	-.000001	.000351
000	0	.989	.00725	40.2	61.7	-.000001	.000358	.989	.00711	40.2	62.7	-.000001	.000351	.989	.00700	40.2	63.6	-.000001	.000345
00	1	.989	.00883	49.9	62.4	-.000001	.000352	.989	.00868	49.9	63.5	-.000001	.000345	.989	.00854	49.9	64.4	-.000001	.000340
0	2	.989	.0108	62.1	63.3	-.000001	.000345	.989	.0106	62.1	64.3	-.000001	.000339	.989	.0104	62.1	65.2	-.000001	.000333
1	3	.989	.0133	77.8	64.2	-.000002	.000340	.989	.0131	77.8	65.2	-.000001	.000333	.989	.0129	77.8	66.2	-.000001	.000329
2	4	.989	.0165	98.0	65.1	-.000002	.000334	.989	.0162	98.0	66.2	-.000002	.000329	.989	.0159	98.0	67.1	-.000002	.000323
3	5	.989	.0205	124.	66.1	-.000002	.000329	.989	.0201	124.	67.2	-.000002	.000323	.989	.0198	124.	68.1	-.000002	.000318
4	6	.989	.0254	156.	67.4	-.000003	.000324	.989	.0249	156.	68.4	-.000003	.000318	.989	.0246	156.	69.4	-.000003	.000313

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for **r**, **x** and **b** as given in Tables VI, XII and XXII, **l** being the length of the circuit in miles. In the value of Y the leakage conductance **gl** is assumed as zero. Values of resistance **r** are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance **x** for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing · Symmetrical triangular spacing · Irregular flat spacing · Regular flat spacing

TABLE XLV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

75 MILES—120.70 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	5 FEET—1.524 METERS						7 FEET—2.134 METERS						9 FEET—2.743 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.988	.001 81	6.95	46.4	.000 000	.000 518	.988	.001 70	6.95	49.4	.000 000	.000 485	.988	.001 62	6.95	51.8	.000 000	.000 462
600 000	.988	.001 94	7.49	46.8	.000 000	.000 514	.988	.001 81	7.49	49.9	.000 000	.000 480	.988	.001 73	7.49	52.1	.000 000	.000 459
550 000	.988	.002 08	8.13	47.2	.000 000	.000 509	.988	.001 95	8.13	50.3	.000 000	.000 476	.988	.001 86	8.13	52.6	.000 000	.000 455
500 000	.988	.002 26	8.90	47.7	.000 000	.000 504	.988	.002 12	8.90	50.7	.000 000	.000 472	.988	.002 03	8.90	53.0	.000 000	.000 451
450 000	.988	.002 48	9.85	48.1	.000 000	.000 499	.988	.002 32	9.85	51.2	.000 000	.000 467	.988	.002 22	9.85	53.5	.000 000	.000 447
400 000	.988	.002 74	11.0	48.9	.000 000	.000 493	.988	.002 57	11.0	51.8	.000 000	.000 462	.988	.002 46	11.0	54.1	.000 000	.000 442
350 000	.988	.003 08	12.6	49.5	-.000 001	.000 486	.988	.002 90	12.6	52.4	.000 000	.000 457	.988	.002 77	12.6	54.7	.000 000	.000 437
300 000	.988	.003 53	14.6	50.1	-.000 001	.000 479	.988	.003 32	14.6	53.2	-.000 001	.000 450	.988	.003 18	14.6	55.4	.000 000	.000 431
250 000	.988	.004 16	17.5	51.0	-.000 001	.000 471	.988	.003 91	17.5	54.0	-.000 001	.000 443	.988	.003 74	17.5	56.2	-.000 001	.000 424
0 000	.988	.004 82	20.7	52.2	-.000 001	.000 463	.988	.004 54	20.7	55.3	-.000 001	.000 436	.988	.004 35	20.7	57.5	-.000 001	.000 417
000	.988	.005 94	26.0	53.3	-.000 001	.000 453	.988	.005 60	26.0	56.4	-.000 001	.000 427	.988	.005 38	26.0	58.6	-.000 001	.000 410
00	.988	.007 32	32.8	54.4	-.000 001	.000 444	.988	.006 92	32.8	57.4	-.000 001	.000 419	.988	.006 65	32.8	59.7	-.000 001	.000 403
0	.988	.009 06	41.3	55.5	-.000 001	.000 435	.988	.008 56	41.3	58.5	-.000 001	.000 411	.988	.008 22	41.3	60.8	-.000 001	.000 395
1	.988	.011 2	52.0	56.6	-.000 002	.000 426	.988	.010 6	52.0	59.6	-.000 001	.000 403	.988	.010 2	52.0	61.9	-.000 001	.000 388
2	.988	.013 8	65.6	57.7	-.000 002	.000 418	.988	.013 1	65.6	60.8	-.000 002	.000 396	.988	.012 6	65.6	63.1	-.000 002	.000 381
3	.988	.017 1	82.7	58.9	-.000 002	.000 411	.988	.016 2	82.7	62.0	-.000 002	.000 389	.988	.015 6	82.7	64.3	-.000 002	.000 374
4	.988	.021 2	104.	60.3	-.000 003	.000 403	.988	.020 1	104.	63.3	-.000 003	.000 382	.988	.019 4	104.	65.6	-.000 002	.000 368

CIRCULAR MILS OR A. W. G. (B & S)	11 FEET—3.353 METERS						13 FEET—3.962 METERS						15 FEET—4.572 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.988	.001 56	6.95	53.5	.000 000	.000 446	.988	.001 52	6.95	55.0	.000 000	.000 432	.988	.001 48	6.95	56.4	.000 000	.000 423
600 000	.988	.001 67	7.49	54.0	.000 000	.000 442	.988	.001 62	7.49	55.5	.000 000	.000 429	.988	.001 59	7.49	56.8	.000 000	.000 420
550 000	.988	.001 80	8.13	54.4	.000 000	.000 439	.988	.001 75	8.13	55.9	.000 000	.000 426	.988	.001 71	8.13	57.2	.000 000	.000 417
500 000	.988	.001 95	8.90	54.8	.000 000	.000 435	.988	.001 90	8.90	56.3	.000 000	.000 423	.988	.001 85	8.90	57.6	.000 000	.000 413
450 000	.988	.002 14	9.85	55.3	.000 000	.000 432	.988	.002 08	9.85	56.8	.000 000	.000 420	.988	.002 04	9.85	58.1	.000 000	.000 410
400 000	.988	.002 38	11.0	55.9	.000 000	.000 427	.988	.002 31	11.0	57.4	.000 000	.000 415	.988	.002 26	11.0	58.8	.000 000	.000 406
350 000	.988	.002 67	12.6	56.5	.000 000	.000 422	.988	.002 60	12.6	58.1	.000 000	.000 411	.988	.002 54	12.6	59.4	.000 000	.000 401
300 000	.988	.003 07	14.6	57.3	.000 000	.000 417	.988	.002 99	14.6	58.8	.000 000	.000 406	.988	.002 92	14.6	60.1	.000 000	.000 397
250 000	.988	.003 63	17.5	58.1	.000 000	.000 411	.988	.003 53	17.5	59.6	.000 000	.000 400	.988	.003 45	17.5	60.9	.000 000	.000 391
0 000	.988	.004 21	20.7	59.4	-.000 001	.000 404	.988	.004 10	20.7	60.9	-.000 001	.000 394	.988	.004 01	20.7	62.2	-.000 001	.000 385
000	.988	.005 20	26.0	60.5	-.000 001	.000 397	.988	.005 07	26.0	62.0	-.000 001	.000 387	.988	.004 96	26.0	63.2	-.000 001	.000 379
00	.988	.006 44	32.8	61.5	-.000 001	.000 390	.988	.006 28	32.8	63.0	-.000 001	.000 380	.988	.006 14	32.8	64.3	-.000 001	.000 372
0	.988	.007 97	41.3	62.6	-.000 001	.000 383	.988	.007 77	41.3	64.1	-.000 001	.000 373	.988	.007 62	41.3	65.4	-.000 001	.000 366
1	.988	.009 87	52.0	63.7	-.000 001	.000 376	.988	.009 64	52.0	65.2	-.000 001	.000 367	.988	.009 43	52.0	66.5	-.000 001	.000 359
2	.988	.012 2	65.6	64.9	-.000 002	.000 370	.988	.011 9	65.6	66.4	-.000 001	.000 361	.988	.011 7	65.6	67.6	-.000 001	.000 354
3	.988	.015 2	82.7	66.1	-.000 002	.000 364	.988	.014 8	82.7	67.6	-.000 002	.000 355	.988	.014 5	82.7	68.9	-.000 002	.000 348
4	.988	.018 8	104.	67.3	-.000 002	.000 358	.988	.018 4	104.	68.8	-.000 002	.000 350	.988	.018 0	104.	70.2	-.000 002	.000 343

CIRCULAR MILS OR A. W. G. (B & S)	17 FEET—5.182 METERS						19 FEET—5.791 METERS						21 FEET—6.401 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.988	.001 45	6.95	57.5	.000 000	.000 414	.988	.001 42	6.95	58.5	.000 000	.000 406	.988	.001 40	6.95	59.4	.000 000	.000 400
600 000	.988	.001 55	7.49	57.9	.000 000	.000 411	.988	.001 52	7.49	58.9	.000 000	.000 403	.988	.001 50	7.49	59.8	.000 000	.000 397
550 000	.988	.001 67	8.13	58.3	.000 000	.000 408	.988	.001 64	8.13	59.3	.000 000	.000 401	.988	.001 62	8.13	60.2	.000 000	.000 394
500 000	.988	.001 82	8.90	58.7	.000 000	.000 405	.988	.001 79	8.90	59.7	.000 000	.000 398	.988	.001 76	8.90	60.6	.000 000	.000 391
450 000	.988	.002 00	9.85	59.2	.000 000	.000 402	.988	.001 96	9.85	60.2	.000 000	.000 394	.988	.001 93	9.85	61.2	.000 000	.000 388
400 000	.988	.002 21	11.0	59.9	.000 000	.000 397	.988	.002 17	11.0	60.9	.000 000	.000 391	.988	.002 14	11.0	61.8	.000 000	.000 385
350 000	.988	.002 49	12.6	60.5	.000 000	.000 394	.988	.002 45	12.6	61.5	.000 000	.000 387	.988	.002 41	12.6	62.4	.000 000	.000 381
300 000	.988	.002 86	14.6	61.2	.000 000	.000 388	.988	.002 82	14.6	62.2	.000 000	.000 382	.988	.002 78	14.6	63.1	.000 000	.000 376
250 000	.988	.003 38	17.5	62.1	.000 000	.000 383	.988	.003 33	17.5	63.1	.000 000	.000 377	.988	.003 28	17.5	63.9	.000 000	.000 371
0 000	.988	.003 94	20.7	63.3	.000 000	.000 378	.988	.003 87	20.7	64.3	.000 000	.000 372	.988	.003 81	20.7	65.2	.000 000	.000 366
000	.988	.004 87	26.0	64.3	-.000 001	.000 371	.988	.004 79	26.0	65.4	-.000 001	.000 365	.988	.004 72	26.0	66.3	-.000 001	.000 360
00	.988	.006 03	32.8	65.4	-.000 001	.000 365	.988	.005 93	32.8	66.5	-.000 001	.000 359	.988	.005 85	32.8	67.4	-.000 001	.000 354
0	.988	.007 48	41.3	66.6	-.000 001	.000 359	.988	.007 35	41.3	67.5	-.000 001	.000 353	.988	.007 26	41.3	68.4	-.000 001	.000 349
1	.988	.009 27	52.0	67.7	-.000 001	.000 353	.988	.009 13	52.0	68.6	-.000 001	.000 348	.988	.008 99	52.0	69.5	-.000 001	.000 343
2	.988	.011 5	65.6	68.8	-.000 001	.000 347	.988	.011 3	65.6	69.8	-.000 001	.000 342	.988	.011 2	65.6	70.7	-.000 001	.000 338
3	.988	.014 3	82.7	70.0	-.000 002	.000 342	.988	.014 0	82.7	71.0	-.000 002	.000 337	.988	.013 9	82.7	71.9	-.000 002	.000 332
4	.988	.017 7	104.	71.3	-.000 002	.000 337	.988	.017 4	104.	72.2	-.000 002	.000 332	.988	.017 2	104.	73.1	-.000 002	.000 328

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE XLVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

75 MILES—120.70 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

5 FEET—1.524 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin. 61%	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00168	5.96	41.3	.000000	.000560
1 113 000	700 000	.988	.00179	6.38	41.5	.000000	.000556
1 033 500	650 000	.988	.00191	6.86	41.8	.000000	.000551
954 000	600 000	.988	.00204	7.42	42.2	.000000	.000546
874 500	550 000	.988	.00221	8.11	42.6	.000000	.000542
795 000	500 000	.988	.00239	8.86	43.0	.000000	.000536
715 500	450 000	.988	.00264	9.90	43.5	.000000	.000530
636 000	400 000	.988	.00293	11.1	44.0	-.000001	.000524
556 500	350 000	.988	.00328	12.5	44.2	-.000001	.000521
477 000	300 000	.988	.00377	14.6	45.0	-.000001	.000513
397 500	250 000	.988	.00444	17.5	45.9	-.000001	.000504
336 400	0 000	.988	.00516	20.7	46.7	-.000001	.000495
266 800	000	.988	.00630	26.1	48.2	-.000001	.000480
0 000	00	.987	.00817	34.5	55.3	-.000001	.000470
000	0	.987	.00997	43.1	56.1	-.000002	.000459
00	1	.987	.0121	53.4	57.0	-.000002	.000450
0	2	.987	.0148	66.4	57.8	-.000002	.000441
1	3	.987	.0182	83.3	58.9	-.000003	.000432
2	4	.987	.0224	105.	59.9	-.000003	.000423

7 FEET—2.134 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00157	5.96	44.3	.000000	.000522
1 113 000	700 000	.988	.00166	6.38	44.6	.000000	.000518
1 033 500	650 000	.988	.00178	6.86	44.9	.000000	.000513
954 000	600 000	.988	.00191	7.42	45.3	.000000	.000510
874 500	550 000	.988	.00207	8.11	45.7	.000000	.000505
795 000	500 000	.988	.00223	8.86	46.0	.000000	.000500
715 500	450 000	.988	.00247	9.90	46.6	.000000	.000495
636 000	400 000	.988	.00274	11.1	47.1	.000000	.000489
556 500	350 000	.988	.00307	12.5	47.3	-.000001	.000487
477 000	300 000	.988	.00353	14.6	48.0	-.000001	.000480
397 500	250 000	.988	.00416	17.5	49.0	-.000001	.000471
336 400	0 000	.988	.00485	20.7	49.7	-.000001	.000465
266 800	000	.988	.00592	26.1	51.2	-.000001	.000451
0 000	00	.987	.00769	34.5	58.3	-.000001	.000442
000	0	.987	.00940	43.1	59.1	-.000001	.000433
00	1	.987	.0114	53.4	60.0	-.000002	.000425
0	2	.987	.0140	66.4	60.9	-.000002	.000417
1	3	.987	.0172	83.3	61.9	-.000002	.000409
2	4	.987	.0212	105.	63.0	-.000003	.000401

9 FEET—2.743 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00149	5.96	46.6	.000000	.000495
1 113 000	700 000	.988	.00158	6.38	46.8	.000000	.000492
1 033 500	650 000	.988	.00169	6.86	47.2	.000000	.000489
954 000	600 000	.988	.00181	7.42	47.6	.000000	.000485
874 500	550 000	.988	.00196	8.11	47.9	.000000	.000480
795 000	500 000	.988	.00213	8.86	48.4	.000000	.000477
715 500	450 000	.988	.00235	9.90	48.8	.000000	.000471
636 000	400 000	.988	.00261	11.1	49.4	.000000	.000466
556 500	350 000	.988	.00293	12.5	49.6	.000000	.000465
477 000	300 000	.988	.00337	14.6	50.3	-.000001	.000458
397 500	250 000	.988	.00397	17.5	51.2	-.000001	.000451
336 400	0 000	.988	.00463	20.7	52.0	-.000001	.000444
266 800	000	.988	.00567	26.1	53.5	-.000001	.000432
0 000	00	.987	.00737	34.5	60.6	-.000001	.000423
000	0	.987	.00901	43.1	61.4	-.000001	.000415
00	1	.987	.0110	53.4	62.3	-.000002	.000408
0	2	.987	.0134	66.4	63.2	-.000002	.000400
1	3	.987	.0165	83.3	64.2	-.000002	.000393
2	4	.987	.0204	105.	65.2	-.000003	.000385

11 FEET—3.353 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00143	5.96	48.4	.000000	.000477
1 113 000	700 000	.988	.00152	6.38	48.7	.000000	.000474
1 033 500	650 000	.988	.00163	6.86	49.0	.000000	.000470
954 000	600 000	.988	.00175	7.42	49.4	.000000	.000467
874 500	550 000	.988	.00189	8.11	49.8	.000000	.000463
795 000	500 000	.988	.00205	8.86	50.1	.000000	.000459
715 500	450 000	.988	.00227	9.90	50.7	.000000	.000455
636 000	400 000	.988	.00251	11.1	51.2	.000000	.000450
556 500	350 000	.988	.00282	12.5	51.4	.000000	.000448
477 000	300 000	.988	.00325	14.6	52.2	.000000	.000442
397 500	250 000	.988	.00383	17.5	53.1	-.000001	.000435
336 400	0 000	.988	.00447	20.7	53.8	-.000001	.000429
266 800	000	.988	.00547	26.1	55.3	-.000001	.000417
0 000	00	.987	.00712	34.5	62.4	-.000001	.000409
000	0	.987	.00873	43.1	63.2	-.000001	.000402
00	1	.987	.0106	53.4	64.0	-.000001	.000394
0	2	.987	.0130	66.4	65.0	-.000002	.000388
1	3	.987	.0160	83.3	66.0	-.000002	.000381
2	4	.987	.0198	105.	66.9	-.000002	.000374

13 FEET—3.962 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00139	5.96	49.9	.000000	.000462
1 113 000	700 000	.988	.00148	6.38	50.2	.000000	.000460
1 033 500	650 000	.988	.00158	6.86	50.5	.000000	.000456
954 000	600 000	.988	.00169	7.42	50.9	.000000	.000453
874 500	550 000	.988	.00184	8.11	51.3	.000000	.000449
795 000	500 000	.988	.00199	8.86	51.7	.000000	.000445
715 500	450 000	.988	.00220	9.90	52.2	.000000	.000441
636 000	400 000	.988	.00244	11.1	52.7	.000000	.000436
556 500	350 000	.988	.00274	12.5	52.9	.000000	.000435
477 000	300 000	.988	.00316	14.6	53.7	.000000	.000430
397 500	250 000	.988	.00373	17.5	54.6	-.000001	.000423
336 400	0 000	.988	.00435	20.7	55.3	-.000001	.000417
266 800	000	.988	.00534	26.1	56.8	-.000001	.000406
0 000	00	.987	.00694	34.5	63.9	-.000001	.000399
000	0	.987	.00850	43.1	64.7	-.000001	.000391
00	1	.987	.0104	53.4	65.6	-.000001	.000385
0	2	.987	.0127	66.4	66.5	-.000002	.000378
1	3	.987	.0156	83.3	67.5	-.000002	.000371
2	4	.987	.0193	105.	68.5	-.000002	.000365

15 FEET—4.572 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00135	5.96	51.3	.000000	.000450
1 113 000	700 000	.988	.00144	6.38	51.6	.000000	.000448
1 033 500	650 000	.988	.00154	6.86	51.9	.000000	.000445
954 000	600 000	.988	.00165	7.42	52.2	.000000	.000442
874 500	550 000	.988	.00179	8.11	52.5	.000000	.000438
795 000	500 000	.988	.00194	8.86	53.0	.000000	.000434
715 500	450 000	.988	.00215	9.90	53.5	.000000	.000430
636 000	400 000	.988	.00238	11.1	54.0	.000000	.000426
556 500	350 000	.988	.00267	12.5	54.3	.000000	.000424
477 000	300 000	.988	.00308	14.6	54.9	.000000	.000419
397 500	250 000	.988	.00363	17.5	55.8	-.000001	.000412
336 400	0 000	.988	.00425	20.7	56.7	-.000001	.000407
266 800	000	.988	.00521	26.1	58.1	-.000001	.000397
0 000	00	.987	.00678	34.5	65.2	-.000001	.000390
000	0	.987	.00832	43.1	66.1	-.000001	.000383
00	1	.987	.0101	53.4	66.9	-.000001	.000376
0	2	.987	.0124	66.4	67.8	-.000002	.000370
1	3	.987	.0153	83.3	68.8	-.000002	.000364
2	4	.987	.0189	105.	69.8	-.000002	.000358

17 FEET—5.182 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00132	5.96	52.4	.000000	.000440
1 113 000	700 000	.988	.00141	6.38	52.7	.000000	.000438
1 033 500	650 000	.988	.00150	6.86	53.0	.000000	.000435
954 000	600 000	.988	.00162	7.42	53.3	.000000	.000432
874 500	550 000	.988	.00175	8.11	53.7	.000000	.000429
795 000	500 000	.988	.00190	8.86	54.1	.000000	.000425
715 500	450 000	.988	.00210	9.90	54.6	.000000	.000421
636 000	400 000	.988	.00233	11.1	55.2	.000000	.000418
556 500	350 000	.988	.00262	12.5	55.4	.000000	.000415
477 000	300 000	.988	.00302	14.6	56.0	.000000	.000410
397 500	250 000	.988	.00356	17.5	57.0	.000000	.000404
336 400	0 000	.988	.00416	20.7	57.8	-.000001	.000399
266 800	000	.988	.00511	26.1	59.2	-.000001	.000389
0 000	00	.987	.00666	34.5	66.4	-.000001	.000382
000	0	.987	.00816	43.1	67.2	-.000001	.000376
00	1	.987	.00996	53.4	68.0	-.000001	.000370
0	2	.987	.0122	66.4	68.9	-.000001	.000363
1	3	.987	.0150	83.3	69.9	-.000002	.000357
2	4	.987	.0186	105.	70.9	-.000002	.000352

19 FEET—5.791 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00130	5.96	53.3	.000000	.000432
1 113 000	700 000	.988	.00138	6.38	53.6	.000000	.000430
1 033 500	650 000	.988	.00148	6.86	53.9	.000000	.000427
954 000	600 000	.988	.00158	7.42	54.3	.000000	.000424
874 500	550 000	.988	.00172	8.11	54.7	.000000	.000421
795 000	500 000	.988	.00186	8.86	55.2	.000000	.000418
715 500	450 000	.988	.00207	9.90	55.6	.000000	.000414
636 000	400 000	.988	.00229	11.1	56.1	.000000	.000410
556 500	350 000	.988	.00257	12.5	56.3	.000000	.000408
477 000	300 000	.988	.00297	14.6	57.1	.000000	.000403
397 500	250 000	.988	.00350	17.5	58.0	.000000	.000398
336 400	0 000	.988	.00409	20.7	58.8	-.000001	.000392
266 800	000	.988	.00502	26.1	60.3	-.000001	.000383
0 000	00	.987	.00654	34.5	67.4	-.000001	.000376
000	0	.987	.00803	43.1	68.2	-.000001	.000370
00	1	.987	.00980	53.4	69.0	-.000001	.000364
0	2	.987	.0120	66.4	69.9	-.000001	.000357
1	3	.987	.0148	83.3	70.9	-.000002	.000352
2	4	.987	.0183	105	71.9	-.000002	.000346

21 FEET—6.401 METERS

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent	A: a_1	A: ja_2	B: b_1	B: jb_2	C: c_1	C: jc_2
1 192 500	750 000	.988	.00128	5.96	54.3	.000000	.000424
1 113 000	700 000	.988	.00136	6.38	54.5	.000000	.000422
1 033 500	650 000	.988	.00145	6.86	54.8	.000000	.000419
954 000	600 000	.988	.00156	7.42	55.2	.000000	.000417
874 500	550 000	.988	.00169	8.11	55.6	.000000	.000414
795 000	500 000	.988	.00183	8.86	56.0	.000000	.000410
715 500	450 000	.988	.00203	9.90	56.5	.000000	.000407
636 000	400 000	.988	.00225	11.1	57.0	.000000	.000403
556 500	350 000	.988	.00253	12.5	57.2	.000000	.000402
477 000	300 000	.988	.00292	14.6	58.0	.000000	.000397
397 500	250 000	.988	.00345	17.5	58.9	.000000	.000392
336 400	0 000	.988	.00403	20.7	59.7	-.000001	.000386
266 800	000	.988	.00494	26.1	61.2	-.000001	.000377
0 000	00	.987	.00645	34.5	68.3	-.000001	.000370
000	0	.987	.00792	43.1	69.0	-.000001	.000364
00	1	.987	.00965	53.4	69.9	-.000001	.000359
0	2	.987	.0118	66.4	70.8	-.000001	.000353
1	3	.987	.0146	83.3	71.8	-.000002	.000347
2	4	.988	.0181	105.	72.8	-.000002	.000341

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XLVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

80 MILES—128.75 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S).	5 FEET—1.524 METERS						7 FEET—2.134 METERS						9 FEET—2.743 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.986	.002 06	7.41	49.5	.000 000	.000 552	.986	.001 93	7.41	52.7	.000 000	.000 517	.986	.001 84	7.41	55.2	.000 000	.000 493
600 000	.986	.002 21	7.98	49.9	.000 000	.000 548	.986	.002 06	7.98	53.2	.000 000	.000 512	.986	.001 97	7.98	55.6	.000 000	.000 489
550 000	.986	.002 37	8.66	50.3	.000000	.000 542	.986	.002 22	8.66	53.6	.000 000	.000 508	.986	.002 12	8.66	56.1	.000 000	.000 485
500 000	.986	.002 57	9.49	50.8	.000 000	.000 538	.986	.002 41	9.49	54.1	.000 000	.000 503	.986	.002 30	9.49	56.5	.000 000	.000 481
450 000	.986	.002 82	10.5	51.3	-.000 001	.000 532	.986	.002 64	10.5	54.6	.000 000	.000 498	.986	.002 52	10.5	57.0	.000 000	.000 476
400 000	.986	.003 12	11.8	52.1	-.000 001	.000 526	.986	.002 93	11.8	55.3	.000 000	.000 493	.986	.002 80	11.8	57.7	.000 000	.000 471
350 000	.986	.003 50	13.4	52.7	-.000 001	.000 518	.986	.003 29	13.4	55.9	-.000 001	.000 487	.986	.003 15	13.4	58.4	.000 000	.000 466
300 000	.986	.004 02	15.6	53.4	-.000 001	.000 511	.986	.003 78	15.6	56.7	-.000 001	.000 480	.986	.003 61	15.6	59.1	-.000 001	.000 459
250 000	.986	.004 73	18.7	54.3	-.000 001	.000 502	.986	.004 45	18.7	57.6	-.000 001	.000 472	.986	.004 26	18.7	60.0	-.000 001	.000 452
0 000	.986	.005 48	22.0	55.7	-.000 001	.000 494	.986	.005 16	22.0	59.0	-.000 001	.000 465	.986	.004 94	22.0	61.4	-.000 001	.000 445
000	.986	.006 76	27.7	56.8	-.000 001	.000 483	.986	.006 37	27.7	60.1	-.000 001	.000 455	.986	.006 11	27.7	62.5	-.000 001	.000 437
00	.986	.008 33	34.9	58.0	-.000 001	.000 473	.986	.007 87	34.9	61.3	-.000 001	.000 447	.986	.007 56	34.9	63.6	-.000 001	.000 429
0	.986	.010 3	44.0	59.2	-.000 002	.000 464	.986	.009 74	44.0	62.4	-.000 001	.000 439	.986	.009 35	44.0	64.8	-.000 001	.000 421
1	.986	.012 7	55.4	60.4	-.000 002	.000 455	.986	.012 0	55.4	63.6	-.000 002	.000 430	.986	.011 6	55.4	66.0	-.000 002	.000 413
2	.986	.015 7	69.9	61.6	-.000 002	.000 446	.986	.014 9	69.9	64.9	-.000 002	.000 422	.986	.014 3	69.9	67.3	-.000 002	.000 406
3	.986	.019 5	88.1	62.9	-.000 003	.000 438	.986	.018 5	88.1	66.2	-.000 003	.000 415	.986	.017 7	88.1	68.6	-.000 002	.000 399
4	.986	.024 1	111.	64.4	-.000 003	.000 429	.986	.022 9	111.	67.6	-.000 003	.000 408	.986	.022 0	111.	70.0	-.000 003	.000 393

CIRCULAR MILS OR A. W. G (B & S).	11 FEET—3.353 METERS						13 FEET—3.962 METERS						15 FEET—4.572 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.986	.001 78	7.41	57.1	.000 000	.000 475	.986	.001 72	7.41	58.7	.000 000	.000 461	.986	.001 68	7.41	60.1	.000 000	.000 451
600 000	.986	.001 90	7.98	57.6	.000 000	.000 471	.986	.001 84	7.98	59.2	.000 000	.000 458	.986	.001 80	7.98	60.5	.000 000	.000 448
550 000	.986	.002 05	8.66	58.0	.000 000	.000 468	.986	.001 99	8.66	59.6	.000 000	.000 455	.986	.001 94	8.66	61.0	.000 000	.000 444
500 000	.986	.002 22	9.49	58.5	.000 000	.000 464	.986	.002 16	9.49	60.0	.000 000	.000 452	.986	.002 11	9.49	61.4	.000 000	.000 440
450 000	.986	.002 44	10.5	58.9	.000 000	.000 460	.986	.002 37	10.5	60.5	.000 000	.000 448	.986	.002 32	10.5	62.0	.000 000	.000 437
400 000	.986	.002 70	11.8	59.6	.000 000	.000 455	.986	.002 63	11.8	61.3	.000 000	.000 443	.986	.002 57	11.8	62.7	.000 000	.000 432
350 000	.986	.003 04	13.4	60.3	.000 000	.000 450	.986	.002 96	13.4	62.0	.000 000	.000 438	.986	.002 89	13.4	63.3	.000 000	.000 428
300 000	.986	.003 50	15.6	61.1	-.000 001	.000 444	.986	.003 40	15.6	62.7	.000 000	.000 432	.986	.003 33	15.6	64.0	.000 000	.000 423
250 000	.986	.004 13	18.7	62.0	-.000 001	.000 438	.986	.004 01	18.7	63.6	-.000 001	.000 426	.986	.003 92	18.7	64.9	-.000 001	.000 416
0 000	.986	.004 79	22.0	63.4	-.000 001	.000 431	.986	.004 66	22.0	64.9	-.000 001	.000 420	.986	.004 56	22.0	66.3	-.000 001	.000 411
000	.986	.005 91	27.7	64.5	-.000 001	.000 423	.986	.005 77	27.7	66.1	-.000 001	.000 412	.986	.005 65	27.7	67.4	-.000 001	.000 404
00	.986	.007 32	34.9	65.6	-.000 001	.000 416	.986	.007 14	34.9	67.2	-.000 001	.000 405	.986	.006 99	34.9	68.6	-.000 001	.000 397
0	.986	.009 07	44.0	66.8	-.000 001	.000 409	.986	.008 84	44.0	68.4	-.000 001	.000 398	.986	.008 66	44.0	69.7	-.000 001	.000 390
1	.986	.011 2	55.4	68.0	-.000 002	.000 401	.986	.011 0	55.4	69.6	-.000 001	.000 392	.986	.010 7	55.4	70.9	-.000 001	.000 383
2	.986	.013 9	69.9	69.2	-.000 002	.000 394	.986	.013 6	69.9	70.8	-.000 002	.000 385	.986	.013 3	69.9	72.1	-.000 002	.000 377
3	.986	.017 3	88.1	70.5	-.000 002	.000 388	.986	.016 8	88.1	72.1	-.000 002	.000 378	.986	.016 5	88.1	73.5	-.000 002	.000 371
4	.986	.021 4	111.	71.9	-.000 003	.000 381	.986	.020 9	111.	73.5	-.000 003	.000 373	.986	.020 5	111.	74.9	-.000 003	.000 366

CIRCULAR MILS OR A. W. G (B & S).	17 FEET—5.182 METERS						19 FEET—5.791 METERS						21 FEET—6.401 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.986	.001 65	7.41	61.3	.000 000	.000 441	.986	.001 62	7.41	62.4	.000 000	.000 433	.986	.001 59	7.41	63.3	.000 000	.000 426
600 000	.986	.001 76	7.98	61.7	.000 000	.000 438	.986	.001 73	7.98	62.8	.000 000	.000 430	.986	.001 71	7.98	63.8	.000 000	.000 424
550 000	.986	.001 90	8.66	62.2	.000 000	.000 435	.986	.001 87	8.66	63.2	.000 000	.000 428	.986	.001 84	8.66	64.2	.000 000	.000 420
500 000	.986	.002 07	9.49	62.6	.000 000	.000 432	.986	.002 03	9.49	63.7	.000 000	.000 424	.986	.002 00	9.49	64.7	.000 000	.000 417
450 000	.986	.002 27	10.5	63.2	.000 000	.000 428	.986	.002 23	10.5	64.2	.000 000	.000 420	.986	.002 19	10.5	65.2	.000 000	.000 414
400 000	.986	.002 52	11.8	63.9	.000 000	.000 424	.986	.002 47	11.8	65.0	.000 000	.000 416	.986	.002 44	11.8	65.9	.000 000	.000 410
350 000	.986	.002 84	13.4	64.5	.000 000	.000 420	.986	.002 79	13.4	65.6	.000 000	.000 412	.986	.002 75	13.4	66.6	.000 000	.000 406
300 000	.986	.003 26	15.6	65.2	.000 000	.000 414	.986	.003 21	15.6	66.3	.000 000	.000 408	.986	.003 16	15.6	67.3	.000 000	.000 401
250 000	.986	.003 85	18.7	66.2	-.000 001	.000 409	.986	.003 79	18.7	67.2	-.000 001	.000 402	.986	.003 73	18.7	68.2	.000 000	.000 396
0 000	.986	.004 48	22.0	67.5	-.000 001	.000 403	.986	.004 40	22.0	68.6	-.000 001	.000 397	.986	.004 33	22.0	69.5	-.000 001	.000 390
000	.986	.005 53	27.7	68.6	-.000 001	.000 396	.986	.005 44	27.7	69.7	-.000 001	.000 389	.986	.005 37	27.7	70.7	-.000 001	.000 384
00	.986	.006 86	34.9	69.8	-.000 001	.000 389	.986	.006 75	34.9	70.9	-.000 001	.000 383	.986	.006 65	34.9	71.8	-.000 001	.000 377
0	.986	.008 50	44.0	71.0	-.000 001	.000 383	.986	.008 36	44.0	72.0	-.000 001	.000 377	.986	.008 25	44.0	73.0	-.000 001	.000 372
1	.986	.010 5	55.4	72.2	-.000 001	.000 377	.986	.010 4	55.4	73.2	-.000 001	.000 371	.986	.010 2	55.4	74.2	-.000 001	.000 366
2	.986	.013 1	69.9	73.4	-.000 002	.000 370	.986	.012 9	69.9	74.4	-.000 002	.000 365	.986	.012 7	69.9	75.4	-.000 002	.000 360
3	.986	.016 2	88.1	74.7	-.000 002	.000 365	.986	.016 0	88.1	75.7	-.000 002	.000 359	.986	.015 8	88.1	76.7	-.000 002	.000 354
4	.986	.020 1	111.	76.1	-.000 002	.000 359	.986	.019 8	111.	77.1	-.000 002	.000 354	.986	.019 6	111.	78.1	-.000 002	.000 350

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XLVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

80 MILES—128.75 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

5 FEET—1.524 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent Circular Mils or A. W. G. based upon Copper 97% Alumin 61%	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 91	6.3[illegible]	44.1	.000 000	.000 597
1 113 000	700 000	.987	.002 03	6.80	44.3	.000 000	.000 593
1 033 500	650 000	.987	.002 17	7.31	44.6	.000 000	.000 588
954 000	600 000	.987	.002 32	7.91	45.0	.000 000	.000 582
874 500	550 000	.987	.002 52	8.64	45.4	.000 000	.000 578
795 000	500 000	.987	.002 72	9.44	45.9	-.000 001	.000 571
715 500	450 000	.987	.003 00	10.6	46.4	-.000 001	.000 565
636 000	400 000	.987	.003 33	11.8	46.9	-.000 001	.000 558
556 500	350 000	.987	.003 73	13.3	47.2	-.000 001	.000 555
477 000	300 000	.987	.004 29	15.5	48.0	-.000 001	.000 546
397 500	250 000	.987	.005 05	18.6	48.9	-.000 001	.000 537
336 400	0 000	.987	.005 87	22.0	49.7	-.000 001	.000 528
266 800	000	.987	.007 16	27.8	51.4	-.000 001	.000 511
0 000	00	.985	.009 29	36.8	58.9	-.000 002	.000 501
000	0	.985	.011 3	45.9	59.8	-.000 002	.000 490
00	1	.985	.013 8	56.9	60.8	-.000 002	.000 480
0	2	.985	.016 8	70.8	61.7	-.000 003	.000 470
1	3	.985	.020 7	88.7	62.9	-.000 003	.000 461
2	4	.986	.025 5	112.	64.0	-.000 004	.000 451

7 FEET—2.134 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 78	6.35	47.2	.000 000	.000 556
1 113 000	700 000	.987	.001 89	6.80	47.6	.000 000	.000 552
1 033 500	650 000	.987	.002 02	7.31	47.9	.000 000	.000 547
954 000	600 000	.987	.002 17	7.91	48.3	.000 000	.000 543
874 500	550 000	.987	.002 35	8.64	48.7	.000 000	.000 538
795 000	500 000	.987	.002 54	9.44	49.1	.000 000	.000 533
715 500	450 000	.987	.002 81	10.6	49.6	.000 000	.000 527
636 000	400 000	.987	.003 11	11.8	50.2	-.000 001	.000 522
556 500	350 000	.987	.003 49	13.3	50.4	-.000 001	.000 519
477 000	300 000	.987	.004 01	15.5	51.2	-.000 001	.000 511
397 500	250 000	.987	.004 73	18.6	52.2	-.000 001	.000 503
336 400	0 000	.987	.005 51	22.0	53.0	-.000 001	.000 495
266 800	000	.987	.006 74	27.8	54.5	-.000 001	.000 481
0 000	00	.985	.008 75	36.8	62.2	-.000 001	.000 471
000	0	.985	.010 7	45.9	63.1	-.000 002	.000 462
00	1	.985	.013 0	56.9	63.9	-.000 002	.000 453
0	2	.986	.015 9	70.8	64.9	-.000 002	.000 444
1	3	.986	.019 5	88.7	66.0	-.000 003	.000 436
2	4	.986	.024 1	112.	67.2	-.000 003	.000 428

9 FEET—2.743 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 69	6.35	49.7	.000 000	.000 528
1 113 000	700 000	.987	.001 80	6.80	49.9	.000 000	.000 525
1 033 500	650 000	.987	.001 92	7.31	50.3	.000 000	.000 521
954 000	600 000	.987	.002 06	7.91	50.8	.000 000	.000 517
874 500	550 000	.987	.002 23	8.64	51.1	.000 000	.000 512
795 000	500 000	.987	.002 42	9.44	51.5	.000 000	.000 508
715 500	450 000	.987	.002 67	10.6	52.0	.000 000	.000 503
636 000	400 000	.987	.002 96	11.8	52.7	.000 000	.000 497
556 500	350 000	.987	.003 33	13.3	52.9	-.000 001	.000 495
477 000	300 000	.987	.003 83	15.5	53.6	-.000 001	.000 488
397 500	250 000	.987	.004 52	18.6	54.6	-.000 001	.000 480
336 400	0 000	.987	.005 26	22.0	55.5	-.000 001	.000 473
266 800	000	.987	.006 45	27.8	57.0	-.000 001	.000 460
0 000	00	.985	.008 38	36.8	64.6	-.000 001	.000 451
000	0	.985	.010 3	45.9	65.4	-.000 002	.000 443
00	1	.985	.012 5	56.9	66.4	-.000 002	.000 435
0	2	.986	.015 2	70.8	67.4	-.000 002	.000 426
1	3	.986	.018 8	88.7	68.5	-.000 003	.000 419
2	4	.986	.023 2	112.	69.6	-.000 003	.000 411

11 FEET—3.353 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 63	6.35	51.6	.000 000	.000 508
1 113 000	700 000	.987	.001 73	6.80	51.9	.000 000	.000 505
1 033 500	650 000	.987	.001 85	7.31	52.3	.000 000	.000 501
954 000	600 000	.987	.001 99	7.91	52.7	.000 000	.000 498
874 500	550 000	.987	.002 15	8.64	53.1	.000 000	.000 493
795 000	500 000	.987	.002 33	9.44	53.5	.000 000	.000 489
715 500	450 000	.987	.002 58	10.6	54.0	.000 000	.000 485
636 000	400 000	.987	.002 86	11.8	54.6	.000 000	.000 480
556 500	350 000	.987	.003 21	13.3	54.8	.000 001	.000 477
477 000	300 000	.987	.003 69	15.5	55.6	-.000 001	.000 471
397 500	250 000	.987	.004 36	18.6	56.6	-.000 001	.000 464
336 400	0 000	.987	.005 09	22.0	57.4	-.000 001	.000 457
266 800	000	.987	.006 22	27.8	58.9	-.000 001	.000 444
0 000	00	.985	.008 10	36.8	66.6	-.000 001	.000 436
000	0	.985	.009 92	45.9	67.4	-.000 001	.000 428
00	1	.986	.012 1	56.9	68.3	-.000 002	.000 420
0	2	.986	.014 8	70.8	69.3	-.000 002	.000 413
1	3	.986	.018 2	88.7	70.4	-.000 002	.000 406
2	4	.986	.022 5	112.	71.6	-.000 003	.000 399

13 FEET—3.962 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 58	6.35	53.2	.000 000	.000 492
1 113 000	700 000	.987	.001 68	6.80	53.5	.000 000	.000 490
1 033 500	650 000	.987	.001 79	7.31	53.8	.000 000	.000 486
954 000	600 000	.987	.001 93	7.91	54.3	.000 000	.000 483
874 500	550 000	.987	.002 09	8.64	54.7	.000 000	.000 479
795 000	500 000	.987	.002 26	9.44	55.1	.000 000	.000 475
715 500	450 000	.987	.002 50	10.6	55.6	.000 000	.000 470
636 000	400 000	.987	.002 77	11.8	56.2	.000 000	.000 465
556 500	350 000	.987	.003 12	13.3	56.4	.000 000	.000 464
477 000	300 000	.987	.003 59	15.5	57.2	-.000 001	.000 458
397 500	250 000	.987	.004 24	18.6	58.2	-.000 001	.000 451
336 400	0 000	.987	.004 94	22.0	59.0	-.000 001	.000 444
266 800	000	.987	.006 07	27.8	60.6	-.000 001	.000 433
0 000	00	.985	.007 89	36.8	68.2	-.000 001	.000 425
000	0	.986	.009 66	45.9	69.0	-.000 001	.000 417
00	1	.986	.011 8	56.9	70.0	-.000 002	.000 410
0	2	.986	.014 4	70.8	70.9	-.000 002	.000 403
1	3	.986	.017 7	88.7	72.0	-.000 002	.000 396
2	4	.986	.022 0	112.	73.1	-.000 003	.000 389

15 FEET—4.572 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 54	6.35	54.6	.000 000	.000 480
1 113 000	700 000	.987	.001 64	6.80	55.0	.000 000	.000 477
1 033 500	650 000	.987	.001 75	7.31	55.3	.000 000	.000 474
954 000	600 000	.987	.001 88	7.91	55.7	.000 000	.000 471
874 500	550 000	.987	.002 04	8.64	56.0	.000 000	.000 467
795 000	500 000	.987	.002 20	9.44	56.5	.000 000	.000 463
715 500	450 000	.987	.002 44	10.6	57.0	.000 000	.000 459
636 000	400 000	.987	.002 71	11.8	57.6	.000 000	.000 454
556 500	350 000	.987	.003 04	13.3	57.8	.000 000	.000 452
477 000	300 000	.987	.003 51	15.5	58.6	-.000 001	.000 447
397 500	250 000	.987	.004 13	18.6	59.5	-.000 001	.000 440
336 400	0 000	.987	.004 83	22.0	60.4	-.000 001	.000 434
266 800	000	.987	.005 92	27.8	62.0	-.000 001	.000 423
0 000	00	.985	.007 71	36.8	69.5	-.000 001	.000 416
000	0	.986	.009 46	45.9	70.5	-.000 001	.000 408
00	1	.986	.011 5	56.9	71.3	-.000 002	.000 401
0	2	.986	.014 1	70.8	72.3	-.000 002	.000 394
1	3	.986	.017 4	88.7	73.4	-.000 002	.000 388
2	4	.986	.021 5	112.	74.5	-.000 003	.000 381

17 FEET—5.182 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 50	6.35	55.8	.000 000	.000 469
1 113 000	700 000	.987	.001 60	6.80	56.2	.000 000	.000 467
1 033 500	650 000	.987	.001 71	7.31	56.5	.000 000	.000 464
954 000	600 000	.987	.001 84	7.91	56.9	.000 000	.000 460
874 500	550 000	.987	.001 99	8.64	57.3	.000 000	.000 457
795 000	500 000	.987	.002 16	9.44	57.7	.000 000	.000 453
715 500	450 000	.987	.002 39	10.6	58.2	.000 000	.000 449
636 000	400 000	.987	.002 65	11.8	58.8	.000 000	.000 445
556 500	350 000	.987	.002 98	13.3	59.0	.000 000	.000 443
477 000	300 000	.987	.003 43	15.5	59.8	-.000 001	.000 437
397 500	250 000	.987	.004 05	18.6	60.7	-.000 001	.000 431
336 400	0 000	.987	.004 73	22.0	61.6	-.000 001	.000 425
266 800	000	.987	.005 81	27.8	63.1	-.000 001	.000 415
0 000	00	.985	.007 57	36.8	70.8	-.000 001	.000 408
000	0	.986	.009 28	45.9	71.6	-.000 001	.000 400
00	1	.986	.011 3	56.9	72.5	-.000 001	.000 394
0	2	.986	.013 8	70.8	73.5	-.000 002	.000 387
1	3	.986	.017 1	88.7	74.6	-.000 002	.000 381
2	4	.986	.021 2	112.	75.7	-.000 003	.000 375

19 FEET—5.791 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 48	6.35	56.9	.000 000	.000 460
1 113 000	700 000	.987	.001 57	6.80	57.2	.000 000	.000 458
1 033 500	650 000	.987	.001 68	7.31	57.5	.000 000	.000 455
954 000	600 000	.987	.001 80	7.91	57.9	.000 000	.000 452
874 500	550 000	.987	.001 96	8.64	58.3	.000 000	.000 448
795 000	500 000	.987	.002 12	9.44	58.8	.000 000	.000 445
715 500	450 000	.987	.002 35	10.6	59.3	.000 000	.000 441
636 000	400 000	.987	.002 61	11.8	59.8	.000 000	.000 437
556 500	350 000	.987	.002 92	13.3	60.1	.000 000	.000 435
477 000	300 000	.987	.003 37	15.5	60.9	.000 000	.000 430
397 500	250 000	.987	.003 98	18.6	61.8	-.000 001	.000 424
336 400	0 000	.987	.004 65	22.0	62.6	-.000 001	.000 418
266 800	000	.987	.005 71	27.8	64.3	-.000 001	.000 408
0 000	00	.986	.007 43	36.8	71.8	-.000 001	.000 400
000	0	.986	.009 13	45.9	72.7	-.000 001	.000 394
00	1	.986	.011 1	56.9	73.6	-.000 001	.000 388
0	2	.986	.013 6	70.8	74.5	-.000 002	.000 381
1	3	.986	.016 8	88.7	75.7	-.000 002	.000 375
2	4	.986	.020 8	112.	76.8	-.000 003	.000 369

21 FEET—6.401 METERS

Circular Mils or A. W. G. (B & S)	Copper Equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.987	.001 45	6.35	57.9	.000 000	.000 452
1 113 000	700 000	.987	.001 54	6.80	58.1	.000 000	.000 450
1 033 500	650 000	.987	.001 65	7.31	58.5	.000 000	.000 447
954 000	600 000	.987	.001 77	7.91	58.9	.000 000	.000 444
874 500	550 000	.987	.001 92	8.64	59.3	.000 000	.000 441
795 000	500 000	.987	.002 08	9.44	59.8	.000 000	.000 437
715 500	450 000	.987	.002 31	10.6	60.2	.000 000	.000 434
636 000	400 000	.987	.002 56	11.8	60.8	.000 000	.000 430
556 500	350 000	.987	.002 88	13.3	61.0	.000 000	.000 429
477 000	300 000	.987	.003 32	15.5	61.8	.000 000	.000 423
397 500	250 000	.987	.003 92	18.6	62.8	-.000 001	.000 417
336 400	0 000	.987	.004 58	22.0	63.7	-.000 001	.000 412
266 800	000	.987	.005 62	27.8	65.2	-.000 001	.000 401
0 000	00	.986	.007 33	36.8	72.8	-.000 001	.000 395
000	0	.986	.009 00	45.9	73.6	-.000 001	.000 389
00	1	.986	.011 0	56.9	74.6	-.000 001	.000 382
0	2	.986	.013 4	70.8	75.5	-.000 002	.000 376
1	3	.986	.016 6	88.7	76.6	-.000 002	.000 370
2	4	.986	.020 5	112.	77.7	-.000 003	.000 364

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5\,040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XLIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

85 MILES—136.80 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	5 FEET—1.524 METERS						7 FEET—2.134 METERS						9 FEET—2.743 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.984	.002 33	7.86	52.5	.000 000	.000 586	.984	.002 18	7.86	56.0	.000 000	.000 549	.985	.002 08	7.86	58.6	.000 000	.000 523
600 000	.984	.002 49	8.47	53.0	.000 000	.000 582	.984	.002 33	8.47	56.5	.000 000	.000 544	.985	.002 22	8.47	59.0	.000 000	.000 519
550 000	.984	.002 68	9.20	53.5	-.000 001	.000 576	.984	.002 51	9.20	56.9	000 000	.000 540	.985	.002 39	9.20	59.5	.000 000	.000 515
500 000	984	.002 90	10.1	54.0	-.000 001	.000 571	.984	.002 72	10.1	57.4	.000 000	.000 534	.985	.002 60	10.1	60.0	.000 000	.000 511
450 000	.984	.003 18	11.1	54.5	-.000 001	.000 565	.984	.002 98	11.1	57.9	-.000 001	.000 529	.985	.002 85	11.1	60.6	.000 000	.000 506
400 000	.984	.003 52	12.5	55.3	-.000 001	.000 558	.984	.003 30	12.5	58.7	-.000 001	.000 523	.985	.003 16	12.5	61.3	-.000 001	.000 501
350 000	.984	.003 95	14.2	56.0	-.000 001	.000 551	.984	.003 72	14.2	59.4	-.000 001	.000 518	.985	.003 55	14.2	62.0	-.000 001	.000 495
300 000	.984	.004 54	16.5	56.8	-.000 001	.000 543	.984	.004 26	16.5	60.2	-.000 001	.000 510	.985	.004 08	16.5	62.8	-.000 001	000 488
250 000	.984	.005 34	19.8	57 7	-.000 001	.000 534	.984	.005 02	19.8	61.2	-.000 001	.000 502	.985	.004 81	19.8	63.7	-.000 001	.000 480
0 000	.984	.006 19	23.4	59.2	- 000 001	.000 524	.984	.005 83	23.4	62.6	-.000 001	.000 494	.984	.005 58	23.4	65.2	-.000 001	.000 473
000	.984	.007 62	29.4	60.4	-.000 001	.000 513	.984	.007 18	29.4	63.8	-.000 001	.000 484	.984	.006 90	29.4	66.4	-.000 001	.000 464
00	.984	.009 40	37.0	61.6	-.000 002	.000 502	.984	.008 88	37.0	65.1	-.000 001	.000 474	.984	.008 53	37.0	67.6	-.000 001	.000 456
0	.984	.011 6	46.7	62.9	-.000 002	.000 493	.984	.011 0	46.7	66.3	-.000 002	.000 466	.984	.010 5	46.7	68.8	-.000 002	.000 447
1	.984	.014 4	58.8	64.1	-.000 002	.000 483	.984	.013 6	58.8	67.6	-.000 002	.000 457	.984	.013 0	58.8	70.1	-.000 002	.000 439
2	.984	.017 8	74.2	65.5	-.000 003	.000 474	.984	.016 8	74.2	68.9	-.000 003	.000 448	.984	.016 2	74.2	71.5	-.000 002	.000 431
3	.984	.022 0	93.6	66.9	-.000 003	.000 465	.984	.020 8	93.6	70.3	-.000 003	.000 441	.984	.020 0	93.6	72.9	-.000 003	.000 424
4	.984	.027 2	118.	68.5	-.000 004	.000 456	.984	.025 8	118.	71.9	-.000 004	.000 433	.984	.024 8	118.	74.5	-.000 003	.000 417

	11 FEET—3.353 METERS						13 FEET—3.962 METERS						15 FEET—4.572 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.985	.002 00	7.86	60.6	.000 000	.000 505	.985	.001 94	7.86	62.3	.000 000	.000 490	.985	.001 90	7.86	63.9	.000 000	.000 479
600 000	.985	.002 14	8.47	61.2	.000 000	.000 501	.985	.002 08	8.47	62.8	.000 000	.000 486	.985	.002 03	8.47	64.3	.000 000	.000 475
550 000	.985	.002 31	9.20	61.6	.000 000	.000 497	.985	.002 24	9.20	63.3	.000 000	.000 483	.985	.002 19	9.20	64.8	.000 000	.000 472
500 000	.985	.002 51	10.1	62.1	.000 000	.000 493	.985	.002 44	10.1	63.8	.000 000	.000 480	.985	.002 38	10.1	65.2	.000 000	.000 468
450 000	.985	.002 75	11.1	62.6	.000 000	.000 489	.985	.002 67	11.1	64.3	.000 000	.000 475	.985	.002 61	11.1	65.8	.000 000	.000 464
400 000	.985	.003 05	12.5	63.4	.000 000	.000 484	.985	.002 97	12.5	65.0	.000 000	.000 470	.985	.002 90	12.5	66.6	.000 000	.000 459
350 000	.985	.003 43	14.2	64.0	-.000 001	.000 478	.985	.003 34	14.2	65.8	-.000 001	.000 465	.985	.003 26	14.2	67.3	.000 000	.000 454
300 000	.985	.003 94	16.5	64.9	-.000 001	.000 472	.985	.003 84	16.5	66.6	-.000 001	.000 459	.985	.003 75	16.5	68.0	-.000 001	.000 449
250 000	.985	.004 65	19.8	65.8	-.000 001	.000 465	.985	.004 52	19.8	67 5	-.000 001	.000 452	.985	.004 42	19.8	69.0	-.000 001	.000 442
0 000	.984	.005 40	23.4	67.3	-.000 001	.000 458	.984	.005 26	23.4	69.0	-.000 001	.000 446	.984	.005 15	23.4	70.4	-.000 001	.000 436
000	.984	.006 62	29.4	68.5	-.000 001	.000 449	.984	.006 51	29.4	70.2	-.000 001	.000 438	.984	.006 37	29.4	71.6	-.000 001	.000 429
00	.984	.008 26	37.0	69.7	-.000 001	.000 441	.984	.008 05	37.0	71.4	-.000 001	.000 430	.984	.007 88	37.0	72.8	-.000 001	.000 421
0	.984	.010 2	46.7	71.0	-.000 001	.000 434	.984	.009 97	46.7	72.6	-.000 001	.000 423	.984	.009 77	46.7	74.1	-.000 001	.000 414
1	.984	.012 7	58.8	72.2	-.000 002	.000 426	.984	.012 4	58.8	73.9	-.000 002	.000 416	.984	.012 1	58.8	75.3	-.000 002	.000 407
2	.984	.015 7	74.2	73.5	-.000 002	.000 419	.984	.015 3	74.2	75.2	-.000 002	.000 408	.984	.015 0	74.2	76.7	-.000 002	.000 401
3	.984	.019 5	93.6	75.0	-.000 003	.000 412	.984	.019 0	93.6	76.6	-.000 003	.000 402	.984	.018 6	93.6	78.1	-.000 002	.000 394
4	.984	.024 1	118.	76.5	-.000 003	.000 405	.984	.023 6	118.	78.2	-.000 003	.000 396	.984	.023 1	118.	79.7	-.000 003	.000 388

	17 FEET—5.182 METERS						19 FEET—5.791 METERS						21 FEET—6.401 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.985	.001 86	7.86	65.1	.000 000	.000 469	.985	.001 83	7.86	66.2	.000 000	.000 460	.985	.001 80	7.86	67.2	.000 000	.000 452
600 000	.985	.001 99	8.47	65.5	.000 000	.000 465	.985	.001 95	8.47	66.7	.000 000	.000 457	.985	.001 93	8.47	67.7	.000 000	.000 450
550 000	.985	.002 14	9.20	66.1	.000 000	.000 462	.985	.002 11	9.20	67.2	.000 000	.000 454	.985	.002 07	9.20	68.2	.000 000	.000 447
500 000	.985	.002 33	10.1	66.5	.000 000	.000 458	.985	.002 29	10.1	67.7	.000 000	.000 451	.985	.002 25	10.1	68.7	.000 000	.000 443
450 000	.985	.002 56	11.1	67.1	.000 000	.000 455	.985	.002 51	11.1	68.2	.000 000	.000 447	.985	.002 47	11.1	69.4	.000 000	.000 440
400 000	.985	.002 84	12.5	67.8	000 000	.000 450	.985	.002 79	12.5	69.0	.000 000	.000 442	.985	.002 75	12.5	70.0	.000 000	.000 436
350 000	.985	.003 20	14.2	68.5	.000 000	.000 446	.985	.003 15	14.2	69.7	.000 000	.000 438	.985	.003 10	14.2	70.7	.000 000	.000 431
300 000	.985	.003 67	16.5	69.3	-.000 001	.000 440	.985	.003 62	16.5	70.5	-.000 001	.000 433	.985	.003 56	16.5	71.5	-.000 001	.000 426
250 000	.985	.004 34	19.8	70.3	-.000 001	.000 434	.985	.004 27	19.8	71.4	-.000 001	.000 427	.985	.004 20	19.8	72.4	-.000 001	.000 420
0 000	.985	.005 05	23.4	71.7	-.000 001	.000 428	.985	.004 97	23.4	72.9	-.000 001	.000 421	.985	.004 89	23.4	73.9	-.000 001	.000 414
000	.985	.006 24	29.4	72.9	-.000 001	.000 420	.985	.006 14	29.4	74.1	-.000 001	.000 414	.985	.006 06	29.4	75.1	-.000 001	.000 408
00	.985	.007 74	37.0	74.1	-.000 001	.000 414	.985	.007 61	37.0	75.3	-.000 001	.000 407	.985	.007 50	37.0	76.3	-.000 001	.000 401
0	.985	.009 59	46.7	75.4	-.000 001	.000 407	.985	.009 43	46.7	76.5	-.000 001	.000 400	.985	.009 31	46.7	77.5	-.000 001	.000 395
1	.985	.011 9	58.8	76.7	-.000 002	.000 400	.985	.011 7	58.8	77.8	-.000 002	.000 394	.985	.011 5	58.8	78.8	-.000 002	.000 388
2	.985	.014 7	74.2	78.0	-.000 002	.000 393	.985	.014 5	74.2	79.1	-.000 002	.000 387	.985	.014 3	74.2	80.1	-.000 002	.000 382
3	.985	.018 3	93.6	79.4	-.000 002	.000 387	.985	.018 0	93.6	80.5	-.000 002	.000 381	.985	.017 8	93.6	81.5	-.000 002	.000 376
4	.985	.022 7	118.	80.9	-.000 003	.000 381	.985	.022 4	118.	82.0	-.000 003	.000 375	.985	.022 1	118.	83.0	-.000 003	.000 371

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40,320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE L—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

85 MILES—136.80 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	5 FEET—1.524 METERS						7 FEET—2.134 METERS						9 FEET—2.743 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.985	.002 16	6.74	46.8	.000000	.000634	.985	.002 01	6.74	50.2	.000000	.000590	.985	.001 91	6.74	52.8	.000000	.000561
1 113 000	700 000	.985	.002 29	7.21	47.0	.000000	.000629	.985	.002 13	7.21	50.5	.000000	.000586	.985	.002 03	7.21	53.0	.000000	.000557
1 033 500	650 000	.985	.002 45	7.76	47.4	-.000001	.000624	.985	.002 28	7.76	50.8	.000000	.000581	.985	.002 17	7.76	53.5	.000000	.000553
954 000	600 000	.985	.002 62	8.39	47.8	-.000001	.000618	.985	.002 44	8.39	51.3	.000000	.000577	.985	.002 33	8.39	53.9	.000000	.000549
874 500	550 000	.985	.002 84	9.17	48.2	-.000001	.000613	.985	.002 65	9.17	51.7	-.000001	.000572	.985	.002 52	9.17	54.2	.000000	.000544
795 000	500 000	.985	.003 07	10.0	48.7	-.000001	.000606	.985	.002 86	10.0	52.1	-.000001	.000566	.985	.002 73	10.0	54.7	.000000	.000540
715 500	450 000	.985	.003 39	11.2	49.2	-.000001	.000600	.985	.003 17	11.2	52.7	-.000001	.000560	.985	.003 02	11.2	55.2	-.000001	.000534
636 000	400 000	.985	.003 75	12.5	49.8	-.000001	.000593	.985	.003 51	12.5	53.3	-.000001	.000554	.985	.003 34	12.5	55.9	-.000001	.000528
556 500	350 000	.985	.004 21	14.1	50.1	-.000001	.000590	.985	.003 94	14.1	53.6	-.000001	.000552	.985	.003 76	14.1	56.2	-.000001	.000526
477 000	300 000	.985	.004 83	16.5	51.0	-.000001	.000580	.985	.004 52	16.5	54.3	-.000001	.000543	.985	.004 32	16.5	56.9	-.000001	.000519
397 500	250 000	.985	.005 69	19.8	52.0	-.000001	.000570	.985	.005 33	19.8	55.4	-.000001	.000534	.985	.005 09	19.8	58.0	-.000001	.000510
336 400	0 000	.985	.006 62	23.4	52.8	-.000001	.000561	.985	.006 21	23.4	56.3	-.000001	.000526	.985	.005 93	23.4	58.9	-.000001	.000502
266 800	000	.985	.008 08	29.5	54.6	-.000001	.000543	.985	.007 60	29.5	57.9	-.000001	.000511	.985	.007 27	29.5	60.5	-.000001	.000489
0 000	00	.983	.010 5	39.0	62.6	-.000002	.000532	.983	.009 87	39.0	66.1	-.000002	.000500	.983	.009 45	39.0	68.6	-.000002	.000479
000	0	.983	.012 8	48.7	63.5	-.000002	.000520	.983	.012 1	48.7	67.0	-.000002	.000490	.984	.011 6	48.7	69.5	-.000002	.000470
00	1	.983	.015 6	60.4	64.6	-.000003	.000510	.984	.014 7	60.4	67.9	-.000002	.000481	.984	.014 1	60.4	70.5	-.000002	.000462
0	2	.984	.018 9	75.1	65.6	-.000003	.000499	.984	.017 9	75.1	69.0	-.000003	.000472	.984	.017 2	75.1	71.6	-.000003	.000452
1	3	.984	.023 3	94.2	66.9	-.000004	.000490	.984	.022 0	94.2	70.2	-.000003	.000462	.984	.021 2	94.2	72.8	-.000003	.000445
2	4	.984	.028 7	119.	68.1	-.000005	.000479	.984	.027 2	119.	71.5	-.000004	.000454	.984	.026 1	119.	74.0	-.000004	.000436

		11 FEET—3.353 METERS						13 FEET—3.962 METERS						15 FEET—4.572 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.985	.001 84	6.74	54.8	.000000	.000540	.985	.001 78	6.74	56.5	.000000	.000523	.985	.001 73	6.74	58.0	.000000	.000509
1 113 000	700 000	.985	.001 95	7.21	55.2	.000000	.000536	.985	.001 89	7.21	56.8	.000000	.000520	.985	.001 85	7.21	58.4	.000000	.000507
1 033 500	650 000	.985	.002 08	7.76	55.5	.000000	.000532	.985	.002 02	7.76	57.2	.000000	.000516	.985	.001 97	7.76	58.7	.000000	.000503
954 000	600 000	.985	.002 24	8.39	55.9	.000000	.000529	.985	.002 17	8.39	57.6	.000000	.000513	.985	.002 12	8.39	59.1	.000000	.000500
874 500	550 000	.985	.002 43	9.17	56.3	.000000	.000524	.985	.002 35	9.17	58.0	.000000	.000508	.985	.002 30	9.17	59.5	.000000	.000496
795 000	500 000	.985	.002 63	10.0	56.8	.000000	.000519	.985	.002 55	10.0	58.5	.000000	.000504	.985	.002 49	10.0	60.0	.000000	.000491
715 500	450 000	.985	.002 91	11.2	57.4	-.000001	.000515	.985	.002 82	11.2	59.1	.000000	.000499	.985	.002 75	11.2	60.6	.000000	.000487
636 000	400 000	.985	.003 22	12.5	58.0	-.000001	.000509	.985	.003 13	12.5	59.6	-.000001	.000494	.985	.003 05	12.5	61.2	.000000	.000482
556 500	350 000	.985	.003 62	14.1	58.2	-.000001	.000507	.985	.003 51	14.1	59.9	-.000001	.000492	.985	.003 43	14.1	61.4	-.000001	.000480
477 000	300 000	.985	.004 16	16.5	59.1	-.000001	.000500	.985	.004 05	16.5	60.8	-.000001	.000486	.985	.003 95	16.5	62.2	-.000001	.000475
397 500	250 000	.985	.004 92	19.8	60.1	-.000001	.000492	.985	.004 78	19.8	61.8	-.000001	.000479	.985	.004 66	19.8	63.2	-.000001	.000467
336 400	0 000	.985	.005 74	23.4	61.0	-.000001	.000486	.985	.005 57	23.4	62.6	-.000001	.000472	.985	.005 45	23.4	64.2	-.000001	.000461
266 800	000	.985	.007 02	29.5	62.6	-.000001	.000472	.985	.006 84	29.5	64.4	-.000001	.000460	.985	.006 68	29.5	65.8	-.000001	.000449
0 000	00	.984	.009 14	39.0	70.7	-.000001	.000463	.984	.008 90	39.0	72.4	-.000001	.000451	.984	.008 70	39.0	73.8	-.000001	.000441
000	0	.984	.011 2	48.7	71.6	-.000002	.000455	.984	.010 9	48.7	73.3	-.000002	.000443	.984	.010 7	48.7	74.8	-.000002	.000434
00	1	.984	.013 6	60.4	72.6	-.000002	.000446	.984	.013 3	60.4	74.3	-.000002	.000435	.984	.013 0	60.4	75.8	-.000002	.000426
0	2	.984	.016 7	75.1	73.6	-.000002	.000439	.984	.016 2	75.1	75.3	-.000002	.000428	.984	.015 9	75.1	76.8	-.000002	.000419
1	3	.984	.020 5	94.2	74.8	-.000003	.000431	.984	.020 0	94.2	76.6	-.000003	.000420	.984	.019 6	94.2	78.0	-.000003	.000412
2	4	.984	.025 4	119.	76.1	-.000004	.000424	.984	.024 8	119.	77.8	-.000003	.000413	.984	.024 3	119.	79.3	-.000003	.000405

		17 FEET—5.182 METERS						19 FEET—5.791 METERS						21 FEET—6.401 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.985	.001 70	6.74	59.3	.000000	.000498	.985	.001 66	6.74	60.4	.000000	.000489	.985	.001 64	6.74	61.5	.000000	.000480
1 113 000	700 000	.985	.001 81	7.21	59.6	.000000	.000496	.985	.001 77	7.21	60.7	.000000	.000486	.985	.001 74	7.21	61.7	.000000	.000478
1 033 500	650 000	.985	.001 93	7.76	60.0	.000000	.000492	.985	.001 89	7.76	61.1	.000000	.000483	.985	.001 86	7.76	62.1	.000000	.000475
954 000	600 000	.985	.002 07	8.39	60.4	.000000	.000489	.985	.002 03	8.39	61.5	.000000	.000480	.985	.002 00	8.39	62.5	.000000	.000472
874 500	550 000	.985	.002 25	9.17	60.8	.000000	.000486	.985	.002 21	9.17	61.9	.000000	.000476	.985	.002 17	9.17	62.9	.000000	.000469
795 000	500 000	.985	.002 43	10.0	61.3	.000000	.000481	.985	.002 39	10.0	62.4	.000000	.000473	.985	.002 35	10.0	63.5	.000000	.000464
715 500	450 000	.985	.002 70	11.2	61.8	.000000	.000477	.985	.002 65	11.2	62.9	.000000	.000469	.985	.002 61	11.2	64.0	.000000	.000461
636 000	400 000	.985	.002 99	12.5	62.4	.000000	.000473	.985	.002 94	12.5	63.5	.000000	.000464	.985	.002 89	12.5	64.5	.000000	.000457
556 500	350 000	.985	.003 36	14.1	62.7	-.000001	.000470	.985	.003 30	14.1	63.8	-.000001	.000462	.985	.003 25	14.1	64.8	.000000	.000455
477 000	300 000	.985	.003 87	16.5	63.5	-.000001	.000464	.985	.003 80	16.5	64.6	-.000001	.000457	.985	.003 74	16.5	65.7	-.000001	.000449
397 500	250 000	.985	.004 57	19.8	64.5	-.000001	.000458	.985	.004 49	19.8	65.7	-.000001	.000450	.985	.004 42	19.8	66.7	-.000001	.000443
336 400	0 000	.985	.005 34	23.4	65.4	-.000001	.000452	.985	.005 25	23.4	66.5	-.000001	.000444	.985	.005 17	23.4	67.6	-.000001	.000437
266 800	000	.985	.006 56	29.5	67.1	-.000001	.000441	.985	.006 44	29.5	68.2	-.000001	.000433	.985	.006 34	29.5	69.3	-.000001	.000426
0 000	00	.984	.008 54	39.0	75.2	-.000001	.000433	.984	.008 39	39.0	76.3	-.000001	.000425	.984	.008 27	39.0	77.3	-.000001	.000419
000	0	.984	.010 5	48.7	76.1	-.000001	.000425	.984	.010 3	48.7	77.2	-.000001	.000419	.984	.010 2	48.7	78.2	-.000001	.000413
00	1	.984	.012 8	60.4	77.0	-.000002	.000419	.984	.012 6	60.4	78.2	-.000002	.000412	.984	.012 4	60.4	79.2	-.000002	.000406
0	2	.984	.015 6	75.1	78.1	-.000002	.000411	.984	.015 3	75.1	79.2	-.000002	.000404	.984	.015 1	75.1	80.2	-.000002	.000399
1	3	.984	.019 2	94.2	79.2	-.000003	.000404	.984	.019 0	94.2	80.4	-.000003	.000398	.984	.018 7	94.2	81.4	-.000002	.000393
2	4	.984	.023 9	119.	80.5	-.000003	.000398	.984	.023 5	119.	81.6	-.000003	.000392	.984	.023 2	119.	82.6	-.000003	.000386

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII. l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE LI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

90 MILES—144.84 KM.

CIRCULAR MILS OR A. W. G (B. & S.)	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																	
	5 FEET—1.524 METERS						7 FEET—2.134 METERS						9 FEET—2.743 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.983	.002 61	8.31	55.6	-.000 001	.000 620	.983	.002 44	8.31	59.2	.000 000	.000 581	.983	.002 33	8.31	62.0	.000 000	.000 554
600 000	.983	.002 79	8.96	56.1	-.000 001	.000 615	.983	.002 61	8.96	59.8	-.000 001	.000 575	.983	.002 49	8.96	62.5	.000 000	.000 549
550 000	.983	.003 00	9.72	56.5	-.000 001	.000 609	.983	.002 81	9.72	60.2	-.000 001	.000 571	.983	.002 68	9.72	63.0	.000 000	.000 545
500 000	.983	.003 25	10.6	57.1	-.000 001	.000 604	.983	.003 05	10.6	60.8	-.000 001	.000 565	.983	.002 91	10.6	63.4	-.000 001	.000 540
450 000	.983	.003 56	11.8	57.6	-.000 001	.000 598	.983	.003 34	11.8	61.3	-.000 001	.000 560	.983	.003 19	11.8	64.1	-.000 001	.000 535
400 000	.983	.003 94	13.2	58.5	-.000 001	.000 590	.983	.003 70	13.2	62.1	-.000 001	.000 554	.983	.003 54	13.2	64.9	-.000 001	.000 530
350 000	.983	.004 43	15.0	59.2	-.000 001	.000 582	.983	.004 16	15.0	62.8	-.000 001	.000 547	.983	.003 98	15.0	65.6	-.000 001	.000 523
300 000	.983	.005 08	17.5	60.1	-.000 001	.000 574	.983	.004 77	17.5	63.7	-.000 001	.000 539	.983	.004 57	17.5	66.4	-.000 001	.000 516
250 000	.983	.005 98	20.9	61.1	-.000 001	.000 564	.983	.005 62	20.9	64.7	-.000 001	.000 530	.983	.005 38	20.9	67.4	-.000 001	.000 508
0 000	.983	.006 93	24.7	62.6	-.000 001	.000 555	.983	.006 53	24.7	66.2	-.000 001	.000 522	.983	.006 25	24.7	68.9	-.000 001	.000 500
000	.983	.008 54	31.1	63.9	-.000 002	.000 543	.983	.008 05	31.1	67.5	-.000 001	.000 512	.983	.007 73	31.1	70.2	-.000 001	.000 491
00	.983	.0105	39.2	65.2	-.000 002	.000 531	.983	.009 94	39.2	68.8	-.000 002	.000 502	.983	.009 55	39.2	71.5	-.000 002	.000 482
0	.983	.0130	49.3	66.5	-.000 002	.000 522	.983	.0123	49.3	70.2	-.000 002	.000 493	.983	.0118	49.3	72.8	-.000 002	.000 473
1	.983	.0161	62.2	67.9	-.000 003	.000 511	.983	.0152	62.2	71.5	-.000 002	.000 483	.983	.0146	62.2	74.2	-.000 002	.000 464
2	.983	.0199	78.4	69.3	-.000 003	.000 501	.983	.0188	78.4	73.0	-.000 003	.000 474	.983	.0181	78.4	75.7	-.000 003	.000 456
3	.983	.0246	98.9	70.9	-.000 004	.000 492	.983	.0233	98.9	74.5	-.000 004	.000 466	.983	.0224	98.9	77.2	-.000 003	.000 448
4	.983	.0304	125.	72.6	-.000 005	.000 482	.983	.0289	125.	75.2	-.000 004	.000 458	.983	.0278	125.	78.9	-.000 004	.000 441

	11 FEET—3.353 METERS						13 FEET—3.962 METERS						15 FEET—4.572 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.983	.002 25	8.31	64.1	.000 000	.000 534	.983	.002 18	8.31	65.9	.000 000	.000 518	.983	.002 13	8.31	67.5	.000 000	.000 506
600 000	.983	.002 40	8.96	64.7	.000 000	.000 530	.983	.002 33	8.96	66.5	.000 000	.000 514	.983	.002 28	8.96	68.0	.000 000	.000 503
550 000	.983	.002 59	9.72	65.1	.000 000	.000 526	.983	.002 51	9.72	66.9	.000 000	.000 511	.983	.002 46	9.72	68.5	.000 000	.000 499
500 000	.983	.002 81	10.6	65.7	.000 000	.000 522	.983	.002 73	10.6	67.5	.000 000	.000 507	.983	.002 66	10.6	69.0	.000 000	.000 495
450 000	.983	.003 08	11.8	66.2	-.000 001	.000 517	.983	.003 00	11.8	68.0	-.000 001	.000 503	.983	.002 93	11.8	69.6	.000 000	.000 491
400 000	.983	.003 42	13.2	67.0	-.000 001	.000 512	.983	.003 32	13.2	68.8	-.000 001	.000 497	.983	.003 24	13.2	70.4	-.000 001	.000 486
350 000	.983	.003 84	15.0	67.7	-.000 001	.000 505	.983	.003 74	15.0	69.6	-.000 001	.000 492	.983	.003 65	15.0	71.1	-.000 001	.000 480
300 000	.983	.004 42	17.5	68.6	-.000 001	.000 499	.983	.004 30	17.5	70.4	-.000 001	.000 486	.983	.004 20	17.5	71.9	-.000 001	.000 475
250 000	.983	.005 21	20.9	69.6	-.000 001	.000 492	.983	.005 07	20.9	71.4	-.000 001	.000 479	.983	.004 96	20.9	72.9	-.000 001	.000 468
0 000	.983	.006 05	24.7	71.2	-.000 001	.000 484	.983	.005 89	24.7	73.0	-.000 001	.000 471	.983	.005 77	24.7	74.5	-.000 001	.000 462
000	.983	.007 47	31.1	72.5	-.000 001	.000 475	.983	.007 29	31.1	74.2	-.000 001	.000 463	.983	.007 13	31.1	75.8	-.000 001	.000 454
00	.983	.009 25	39.2	73.7	-.000 001	.000 467	.983	.009 02	39.2	75.5	-.000 001	.000 455	.983	.008 83	39.2	77.1	-.000 001	.000 446
0	.983	.0115	49.3	75.1	-.000 002	.000 459	.983	.0112	49.3	76.9	-.000 002	.000 447	.983	.0109	49.3	78.4	-.000 002	.000 438
1	.983	.0142	62.2	76.4	-.000 002	.000 451	.983	.0139	62.2	78.2	-.000 002	.000 440	.983	.0135	62.2	79.7	-.000 002	.000 430
2	.983	.0176	78.4	77.8	-.000 003	.000 443	.983	.0172	78.4	79.6	-.000 002	.000 432	.983	.0168	78.4	81.1	-.000 002	.000 424
3	.983	.0218	98.9	79.4	-.000 003	.000 436	.983	.0213	98.9	81.1	-.000 003	.000 425	.983	.0209	98.9	82.7	-.000 003	.000 417
4	.983	.0270	125.	81.0	-.000 004	.000 429	.983	.0264	125.	82.8	-.000 004	.000 419	.983	.0259	125.	84.4	-.000 004	.000 411

	17 FEET—5.182 METERS						19 FEET—5.791 METERS						21 FEET—6.401 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.983	.002 08	8.31	68.9	.000 000	.000 496	.983	.002 05	8.31	70.1	.000 000	.000 487	.983	.002 01	8.31	71.1	.000 000	.000 479
600 000	.983	.002 23	8.96	69.3	.000 000	.000 492	.983	.002 19	8.96	70.6	.000 000	.000 483	.983	.002 16	8.96	71.7	.000 000	.000 476
550 000	.983	.002 40	9.72	69.9	.000 000	.000 488	.983	.002 36	9.72	71.0	.000 000	.000 480	.983	.002 32	9.72	72.1	.000 000	.000 472
500 000	.983	.002 61	10.6	70.3	.000 000	.000 485	.983	.002 57	10.6	71.6	.000 000	.000 477	.983	.002 53	10.6	72.7	.000 000	.000 469
450 000	.983	.002 87	11.8	71.0	.000 000	.000 481	.983	.002 81	11.8	72.1	.000 000	.000 472	.983	.002 77	11.8	73.3	.000 000	.000 465
400 000	.983	.003 18	13.2	71.8	-.000 001	.000 476	.983	.003 12	13.2	73.0	.000 000	.000 468	.983	.003 08	13.2	74.1	.000 000	.000 461
350 000	.983	.003 59	15.0	72.5	-.000 001	.000 471	.983	.003 52	15.0	73.7	-.000 001	.000 463	.983	.003 47	15.0	74.8	-.000 001	.000 456
300 000	.983	.004 11	17.5	73.3	-.000 001	.000 465	.983	.004 05	17.5	74.5	-.000 001	.000 458	.983	.003 99	17.5	75.6	-.000 001	.000 451
250 000	.983	.004 86	20.9	74.4	-.000 001	.000 459	.983	.004 79	20.9	75.5	-.000 001	.000 452	.983	.004 71	20.9	76.6	-.000 001	.000 445
0 000	.983	.005 66	24.7	75.8	-.000 001	.000 453	.983	.005 56	24.7	77.1	-.000 001	.000 446	.983	.005 48	24.7	78.1	-.000 001	.000 438
000	.983	.006 99	31.1	77.1	-.000 001	.000 445	.983	.006 88	31.1	78.3	-.000 001	.000 437	.983	.006 78	31.1	79.4	-.000 001	.000 431
00	.983	.008 67	39.2	78.4	-.000 001	.000 437	.983	.008 53	39.2	79.6	-.000 001	.000 430	.983	.008 40	39.2	80.7	-.000 001	.000 424
0	.983	.0107	49.3	79.8	-.000 002	.000 430	.983	.0106	49.3	81.0	-.000 002	.000 423	.983	.0104	49.3	82.0	-.000 001	.000 418
1	.983	.0133	62.2	81.2	-.000 002	.000 423	.983	.0131	62.2	82.3	-.000 002	.000 417	.983	.0129	62.2	83.4	-.000 002	.000 411
2	.983	.0165	78.4	82.6	-.000 002	.000 416	.983	.0163	78.4	83.7	-.000 002	.000 410	.983	.0160	78.4	84.8	-.000 002	.000 404
3	.983	.0205	98.9	84.1	-.000 003	.000 410	.983	.0202	98.9	85.2	-.000 003	.000 403	.983	.0199	98.9	86.3	-.000 003	.000 398
4	.983	.0255	125.	85.7	-.000 003	.000 403	.983	.0251	125.	86.8	-.000 003	.000 397	.983	.0248	125.	87.9	-.000 003	.000 393

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

90 MILES—144.84 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

Circular Mils or A W G (B & S)	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin 61%	5 Feet—1.524 Meters						7 Feet—2.134 Meters						9 Feet—2.743 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.983	.002 42	7.13	49.5	-.000001	.000 671	.983	.002 25	7.13	53.1	.000 000	.000 625	.983	.002 14	7.13	55.9	.000 000	.000 593
1 113 000	700 000	.983	.002 57	7.63	49.8	-.000001	.000 666	.983	.002 39	7.63	53.4	.000 000	.000 620	.983	.002 27	7.63	56.1	.000 000	.000 590
1 033 500	650 000	.983	.002 74	8.21	50.1	-.000001	.000 661	.983	.002 55	8.21	53.8	-.000 001	.000 615	.983	.002 43	8.21	56.6	.000 000	.000 585
954 000	600 000	.983	.002 94	8.87	50.6	-.000001	.000 654	.983	.002 74	8.87	54.3	-.000001	.000 610	.983	.002 61	8.87	57.0	-.000 001	.000 581
874 500	550 000	.983	.003 18	9.70	51.0	-.000 001	.000 649	.983	.002 97	9.70	54.7	-.000001	.000 605	.983	.002 82	9.70	57.4	-.000 001	.000 576
795 000	500 000	.983	.003 44	10.6	51.6	-.000 001	.000 642	.983	.003 21	10.6	55.1	-.000 001	.000 599	.983	.003 06	10.6	57.9	-.000001	.000 571
715 500	450 000	.983	.003 80	11.8	52.1	-.000 001	.000 635	.983	.003 55	11.8	55.8	-.000001	.000 593	.983	.003 38	11.8	58.5	-.000001	.000 565
636 000	400 000	.983	.004 20	13.3	52.7	-.000001	.000 627	.983	.003 93	13.3	56.4	-.000001	.000 586	.983	.003 74	13.3	59.2	-.000 001	.000 559
556 500	350 000	.983	.004 72	15.0	53.0	-.000001	.000 624	.983	.004 41	15.0	56.7	-.000001	.000 584	.983	.004 21	15.0	59.5	-.000001	.000 557
477 000	300 000	.983	.005 42	17.4	53.9	-.000001	.000 614	.983	.005 07	17.4	57.5	-.000001	.000 575	.983	.004 84	17.4	60.3	-.000001	.000 549
397 500	250 000	.983	.006 38	20.9	55.0	-.000001	.000 603	.983	.005 97	20.9	58.7	-.000001	.000 565	.983	.005 71	20.9	61.4	-.000001	.000 540
336 400	0 000	.983	.007 42	24.7	55.9	-.000001	.000 593	.983	.006 96	24.7	59.6	-.000001	.000 557	.983	.006 65	24.7	62.4	-.000001	.000 532
266 800	000	.983	.009 05	31.2	57.7	-.000002	.000 575	.983	.008 51	31.2	61.3	-.000002	.000 541	.983	.008 15	31.2	64.1	-.000 001	.000 517
0 000	00	.981	.011 8	41.2	66.3	-.000002	.000 563	.981	.011 1	41.2	69.9	-.000002	.000 530	.981	.010 6	41.2	72.6	-.000 002	.000 507
000	0	.981	.014 3	51.5	67.2	-.000003	.000 550	.981	.013 5	51.5	70.9	-.000002	.000 519	.982	.013 0	51.5	73.6	-.000002	.000 497
00	1	.981	.017 4	63.8	68.4	-.000003	.000 539	.982	.016 4	63.8	71.9	-.000003	.000 509	.982	.015 8	63.8	74.7	-.000003	.000 488
0	2	.982	.021 2	79.4	69.5	-.000004	.000 528	.982	.020 1	79.4	73.1	-.000003	.000 499	.982	.019 2	79.4	75.8	-.000003	.000 479
1	3	.982	.026 1	99.6	70.8	-.000005	.000 518	.982	.024 7	99.6	74.4	-.000 004	.000 489	.982	.023 7	99.6	77.1	-.000004	.000 471
2	4	.982	.032 2	125.	72.2	-.000005	.000 507	.982	.030 5	125.	75.8	-.000005	.000 480	.982	.029 3	125.	78.4	-.000005	.000 462

Circular Mils or A W G (B & S)	Copper Equivalent	11 Feet—3.353 Meters						13 Feet—3.962 Meters						15 Feet—4.572 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.983	.002 06	7.13	58.0	.000000	.000 571	.983	.001 99	7.13	59.8	.000 000	.000 553	.983	.001 94	7.13	61.4	.000000	.000 539
1 113 000	700 000	.983	.002 19	7.63	58.4	.000 000	.000 567	.983	.002 12	7.63	60.2	.000 000	.000 550	.983	.002 07	7.63	61.8	.000000	.000 536
1 033 500	650 000	.983	.002 34	8.21	58.7	.000 000	.000 563	.983	.002 27	8.21	60.5	.000 000	.000 546	.983	.002 21	8.21	62.1	.000000	.000 533
954 000	600 000	.983	.002 51	8.87	59.2	.000 000	.000 559	.983	.002 43	8.87	61.0	.000 000	.000 542	.983	.002 37	8.87	62.6	.000000	.000 529
874 500	550 000	.983	.002 72	9.70	59.6	-.000001	.000 554	.983	.002 64	9.70	61.4	.000 000	.000 538	.983	.002 57	9.70	62.9	.000000	.000 525
795 000	500 000	.983	.002 94	10.6	[illegible]0.1	-.000001	.000 550	.983	.002 86	10.6	61.9	-.000001	.000 533	.983	.002 78	10.6	63.5	.000000	.000 520
715 500	450 000	.983	.003 26	11.8	60.7	-.000001	.000 545	.983	.003 16	11.8	62.5	-.000001	.000 528	.983	.003 09	11.8	64.1	-.000 001	.000 516
636 000	400 000	.983	.003 61	13.3	61.3	-.000001	.000 539	.983	.003 50	13.3	63.1	-.000001	.000 523	.983	.003 42	13.3	64.7	-.000001	.000 510
556 500	350 000	.983	.004 05	15.0	61.6	-.000001	.000 536	.983	.003 94	15.0	63.4	-.000001	.000 521	.983	.003 84	15.0	65.0	-.000001	.000 508
477 000	300 000	.983	.004 66	17.4	62.5	-.000001	.000 529	.983	.004 54	17.4	64.3	-.000001	.000 515	.983	.004 43	17.4	65.8	-.000 001	.000 502
397 500	250 000	.983	.005 51	20.9	63.6	-.000001	.000 521	.983	.005 36	20.9	65.4	-.000001	.000 507	.983	.005 22	20.9	66.9	-.000 001	.000 494
336 400	0 000	.983	.006 43	24.7	64.5	-.000001	.000 514	.983	.006 25	24.7	66.3	-.000001	.000 499	.983	.006 10	24.7	67.9	-.000001	.000 488
266 800	000	.983	.007 87	31.2	66.2	-.000001	.000 499	.983	.007 67	31.2	68.1	-.000001	.000 487	.983	.007 49	31 2	69.6	-.000001	.000 475
0 000	00	.982	.010 2	41.2	74.8	-.000002	.000 490	.982	.009 97	41.2	76.6	-.000002	.000 478	.982	.009 75	41.2	78.1	-.000 002	.000 467
000	0	.982	.012 5	51.5	75.8	-.000002	.000 481	.982	.012 2	51.5	77.6	-.000 002	.000 469	.982	.012 0	51.5	79.2	-.000002	.000 459
00	1	.982	.015 3	63.8	76.8	-.000002	.000 472	.982	.014 9	63.8	78.7	-.000002	.000 461	.982	.014 6	63.8	80.2	-.000 002	.000 451
0	2	.982	.018 7	79.4	78.0	-.000 003	.000 464	.982	.018 2	79.4	79.8	-.000003	.000 453	.982	.017 8	79.4	81.4	-.000 003	.000 443
1	3	.982	.023 0	99.6	79.2	-.000 004	.000 456	.982	.022 4	99.6	81.1	-.000003	.000 445	.982	.022 0	99.6	82.6	-.000 003	.000 436
2	4	.982	.028 4	125.	80.6	-.000 004	.000 448	.982	.027 8	125.	82.4	-.000 004	.000 438	.982	.027 2	125.	84.0	-.000 004	.000 429

Circular Mils or A W G (B & S)	Copper Equivalent	17 Feet—5.182 Meters						19 Feet—5.791 Meters						21 Feet—6.401 Meters					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 192 500	750 000	.983	.001 90	7.13	62.7	.000000	.000 527	.983	.001 87	7.13	63.9	.000 000	.000 517	.983	.001 83	7.13	65.1	.000 000	.000 508
1 113 000	700 000	.983	.002 02	7.63	63.1	.000000	.000 525	.983	.001 99	7.63	64.3	.000 000	.000 515	.983	.001 95	7.63	65.4	.000 000	.000 506
1 033 500	650 000	.983	.002 16	8.21	63.5	.000000	.000 521	.983	.002 12	8.21	64.6	.000 000	.000 511	.983	.002 08	8.21	65.7	.000000	.000 502
954 000	600 000	.983	.002 32	8.87	63.9	.000 000	.000 517	.983	.002 28	8.87	65.1	.000 000	.000 508	.983	.002 24	8.87	66.2	.000 000	.000 499
874 500	550 000	.983	.002 52	9.70	64.4	.000 000	.000 514	.983	.002 47	9.70	65.5	.000 000	.000 504	.983	.002 43	9.70	66.6	.000000	.000 496
795 000	500 000	.983	.002 73	10.6	64.8	.000 000	.000 509	.983	.002 68	10.6	66.1	.000 000	.000 500	.983	.002 63	10.6	67.1	.000 000	.000 491
715 500	450 000	.983	.003 02	11.8	65.4	-.000 001	.000 505	.983	.002 97	11.8	66.6	.000 000	.000 496	.983	.002 92	11.8	67.7	.000 000	.000 488
636 000	400 000	.983	.003 35	13.3	66.1	-.000001	.000 500	.983	.003 29	13.3	67.2	-.000 001	.000 491	.983	.003 24	13.3	68.3	-.000 001	.000 483
556 500	350 000	.983	.003 76	15.0	66.3	-.000 001	.000 498	.983	.003 69	15.0	67.5	-.000 001	.000 489	.983	.003 64	15.0	68.6	-.000001	.000 482
477 000	300 000	.983	.004 33	17.4	67.2	-.000 001	.000 491	.983	.004 26	17.4	68.4	-.000 001	.000 483	.983	.004 19	17.4	69.5	-.000001	.000 475
397 500	250 000	.983	.005 12	20.9	68.2	-.000 001	.000 484	.983	.005 03	20.9	69.5	-.000 001	.000 476	.983	.004 96	20.9	70.6	-.000001	.000 469
336 400	0 000	.983	.005 98	24.7	69.2	-.000 001	.000 478	.983	.005 88	24.7	70.4	-.000 001	.000 470	.983	.005 79	24.7	71.6	-.000 001	.000 463
266 800	000	.983	.007 35	31.2	71.0	-.000 001	.000 466	.983	.007 22	31.2	72.2	-.000001	.000 458	.983	.007 10	31.2	73.3	-.000 001	.000 451
0 000	00	.982	.009 56	41.2	79.6	-.000 001	.000 458	.982	.009 39	41.2	80.7	-.000001	.000 450	.982	.009 26	41.2	81.8	-.000 001	.000 444
000	0	.982	.011 7	51.5	80.5	-.000002	.000 450	.982	.011 5	51.5	81.7	-.000002	.000 443	.982	.011 4	51.5	82.8	-.000002	.000 437
00	1	.982	.014 3	63.8	81.5	-.000002	.000 443	.982	.013 9	63.8	82.8	-.000 002	.000 436	.982	.013 7	63.8	83.9	-.000 002	.000 429
0	2	.982	.017 5	79.4	82.7	-.000003	.000 435	.982	.017 2	79.4	83.8	-.000 002	.000 428	.982	.017 0	79.4	84.9	-.000 002	.000 422
1	3	.982	.021 6	99.6	83.9	-.000003	.000 428	.982	.021 2	99.6	85.2	-.000 003	.000 421	.982	.021 0	99.6	86.2	-.000003	.000 416
2	4	.982	.026 7	125.	85.3	-.000004	.000 421	.982	.026 3	125.	86.5	-.000 004	.000 414	.982	.025 9	125.	87.5	-.000 004	.000 409

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $\quad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $\quad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$.

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

95 MILES—152.89 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

5 FEET—1.524 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 90	8.76	58.6	-.000 001	.000 654
600 000	.981	.003 11	9.44	59.2	-.000 001	.000 649
550 000	.981	.003 34	10.3	59.7	-.000 001	.000 643
500 000	.981	.003 62	11.2	60.2	-.000 001	.000 637
450 000	.981	.003 97	12.4	60.8	-.000 001	.000 631
400 000	.981	.004 39	13.9	61.8	-.000 001	.000 623
350 000	.981	.004 93	15.8	62.5	-.000 001	.000 615
300 000	.981	.005 66	18.4	63.4	-.000 001	.000 606
250 000	.981	.006 66	22.1	64.3	-.000 001	.000 596
0 000	.981	.007 72	26.0	66.1	-.000 002	.000 585
000	.981	.009 51	32.8	67.4	-.000 002	.000 573
00	.981	.011 7	41.3	68.8	-.000 002	.000 561
0	.981	.014 5	52.0	70.2	-.000 003	.000 550
1	.981	.017 9	65.6	71.7	-.000 003	.000 539
2	.981	.022 2	82.7	73.2	-.000 004	.000 529
3	.980	.027 4	104.	74.9	-.000 005	.000 519
4	.980	.033 9	131.	75.2	-.000 006	.000 509

7 FEET—2.134 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 72	8.76	62.5	-.000 001	.000 613
600 000	.981	.002 90	9.44	63.1	-.000 001	.000 607
550 000	.981	.003 13	10.3	63.5	-.000 001	.000 602
500 000	.981	.003 39	11.2	64.1	-.000 001	.000 597
450 000	.981	.003 72	12.4	64.7	-.000 001	.000 591
400 000	.981	.004 12	13.9	65.5	-.000 001	.000 584
350 000	.981	.004 64	15.8	66.3	-.000 001	.000 578
300 000	.981	.005 31	18.4	67.2	-.000 001	.000 569
250 000	.981	.006 26	22.1	68.3	-.000 001	.000 560
0 000	.981	.007 27	26.0	69.9	-.000 001	.000 551
000	.981	.008 96	32.8	71.3	-.000 002	.000 540
00	.981	.011 1	41.3	72.7	-.000 002	.000 530
0	.981	.013 7	52.0	74.1	-.000 002	.000 520
1	.981	.016 9	65.6	75.5	-.000 003	.000 510
2	.981	.021 0	82.7	77.1	-.000 004	.000 500
3	.981	.026 0	104.	78.7	-.000 004	.000 492
4	.981	.032 2	131.	80.5	-.000 005	.000 483

9 FEET—2.743 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 59	8.76	65.4	-.000 001	.000 584
600 000	.981	.002 77	9.44	65.9	-.000 001	.000 580
550 000	.981	.002 98	10.3	66.5	-.000 001	.000 575
500 000	.981	.003 24	11.2	66.9	-.000 001	.000 570
450 000	.981	.003 55	12.4	67.6	-.000 001	.000 565
400 000	.981	.003 94	13.9	68.5	-.000 001	.000 559
350 000	.981	.004 43	15.8	69.2	-.000 001	.000 552
300 000	.981	.005 08	18.4	70.1	-.000 001	.000 545
250 000	.981	.006 00	22.1	71.1	-.000 001	.000 536
0 000	.981	.006 96	26.0	72.7	-.000 001	.000 528
000	.981	.008 60	32.8	74.1	-.000 002	.000 518
00	.981	.010 6	41.3	75.5	-.000 002	.000 509
0	.981	.013 2	52.0	76.9	-.000 002	.000 499
1	.981	.016 3	65.6	78.3	-.000 003	.000 490
2	.981	.020 2	82.7	80.0	-.000 003	.000 481
3	.981	.025 0	104.	81.6	-.000 004	.000 473
4	.981	.031 0	131.	83.4	-.000 005	.000 465

11 FEET—3.353 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 50	8.76	67.7	.000 000	.000 564
600 000	.981	.002 67	9.44	68.3	-.000 001	.000 559
550 000	.981	.002 88	10.3	68.7	-.000 001	.000 555
500 000	.981	.003 13	11.2	69.3	-.000 001	.000 550
450 000	.981	.003 43	12.4	69.9	-.000 001	.000 546
400 000	.981	.003 81	13.9	70.7	-.000 001	.000 540
350 000	.981	.004 28	15.8	71.5	-.000 001	.000 533
300 000	.981	.004 92	18.4	72.4	-.000 001	.000 527
250 000	.981	.005 81	22.1	73.5	-.000 001	.000 519
0 000	.981	.006 73	26.0	75.1	-.000 001	.000 511
000	.981	.008 32	32.8	76.5	-.000 001	.000 501
00	.981	.010 3	41.3	77.8	-.000 002	.000 493
0	.981	.012 8	52.0	79.2	-.000 002	.000 484
1	.981	.015 8	65.6	80.7	-.000 003	.000 476
2	.981	.019 6	82.7	82.2	-.000 003	.000 467
3	.981	.024 3	104.	83.8	-.000 004	.000 460
4	.981	.030 1	131.	85.6	-.000 005	.000 452

13 FEET—3.962 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 43	8.76	69.6	.000 000	.000 547
600 000	.981	.002 60	9.44	70.1	.000 000	.000 543
550 000	.981	.002 80	10.3	70.6	-.000 001	.000 539
500 000	.981	.003 04	11.2	71.2	-.000 001	.000 535
450 000	.981	.003 34	12.4	71.8	-.000 001	.000 531
400 000	.981	.003 70	13.9	72.6	-.000 001	.000 525
350 000	.981	.004 17	15.8	73.5	-.000 001	.000 519
300 000	.981	.004 79	18.4	74.3	-.000 001	.000 513
250 000	.981	.005 65	22.1	75.4	-.000 001	.000 505
0 000	.981	.006 56	26.0	77.0	-.000 001	.000 497
000	.981	.008 12	32.8	78.3	-.000 001	.000 489
00	.981	.010 0	41.3	79.7	-.000 002	.000 480
0	.981	.012 4	52.0	81.1	-.000 002	.000 472
1	.981	.015 4	65.6	82.6	-.000 002	.000 464
2	.981	.019 1	82.7	84.1	-.000 003	.000 456
3	.981	.023 7	104.	85.7	-.000 004	.000 448
4	.981	.029 4	131.	87.5	-.000 004	.000 442

15 FEET—4.572 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 37	8.76	71.3	.000 000	.000 534
600 000	.981	.002 54	9.44	71.8	.000 000	.000 531
550 000	.981	.002 73	10.3	72.3	.000 000	.000 527
500 000	.981	.002 97	11.2	72.8	-.000 001	.000 522
450 000	.981	.003 26	12.4	73.5	-.000 001	.000 518
400 000	.981	.003 61	13.9	74.3	-.000 001	.000 513
350 000	.981	.004 07	15.8	75.1	-.000 001	.000 507
300 000	.981	.004 68	18.4	75.9	-.000 001	.000 501
250 000	.981	.005 52	22.1	77.0	-.000 001	.000 494
0 000	.981	.006 42	26.0	78.6	-.000 001	.000 487
000	.981	.007 95	32.8	80.0	-.000 001	.000 479
00	.981	.009 83	41.3	81.3	-.000 002	.000 470
0	.981	.012 2	52.0	82.7	-.000 002	.000 463
1	.981	.015 1	65.6	84.2	-.000 002	.000 454
2	.981	.018 7	82.7	85.7	-.000 003	.000 447
3	.981	.023 2	104.	87.4	-.000 003	.000 440
4	.981	.028 9	131.	89.2	-.000 004	.000 433

17 FEET—5.182 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 32	8.76	72.7	.000 000	.000 523
600 000	.981	.002 48	9.44	73.2	.000 000	.000 519
550 000	.981	.002 68	10.3	73.7	.000 000	.000 515
500 000	.981	.002 91	11.2	74.2	-.000 001	.000 512
450 000	.981	.003 19	12.4	74.9	-.000 001	.000 508
400 000	.981	.003 54	13.9	75.7	-.000 001	.000 502
350 000	.981	.003 99	15.8	76.5	-.000 001	.000 497
300 000	.981	.004 58	18.4	77.3	-.000 001	.000 491
250 000	.981	.005 42	22.1	78.5	-.000 001	.000 484
0 000	.981	.006 30	26.0	80.0	-.000 001	.000 478
000	.981	.007 79	32.8	81.4	-.000 001	.000 469
00	.981	.009 65	41.3	82.7	-.000 001	.000 462
0	.981	.012 0	52.0	84.2	-.000 002	.000 454
1	.981	.014 8	65.6	85.7	-.000 002	.000 447
2	.981	.018 4	82.7	87.2	-.000 003	.000 439
3	.981	.022 8	104.	88.8	-.000 003	.000 432
4	.981	.028 4	131.	90.6	-.000 004	.000 426

19 FEET—5.791 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 28	8.76	73.9	.000 000	.000 514
600 000	.981	.002 44	9.44	74.5	.000 000	.000 510
550 000	.981	.002 63	10.3	75.0	.000 000	.000 507
500 000	.981	.002 86	11.2	75.5	.000 000	.000 503
450 000	.981	.003 13	12.4	76.1	-.000 001	.000 498
400 000	.981	.003 48	13.9	77.0	-.000 001	.000 494
350 000	.981	.003 93	15.8	77.8	-.000 001	.000 489
300 000	.981	.004 52	18.4	78.7	-.000 001	.000 483
250 000	.981	.005 33	22.1	79.7	-.000 001	.000 477
0 000	.981	.006 20	26.0	81.3	-.000 001	.000 470
000	.981	.007 66	32.8	82.7	-.000 001	.000 462
00	.981	.009 50	41.3	84.1	-.000 001	.000 454
0	.981	.011 8	52.0	85.5	-.000 002	.000 447
1	.981	.014 6	65.6	86.9	-.000 002	.000 440
2	.981	.018 1	82.7	88.4	-.000 003	.000 432
3	.981	.022 5	104.	90.0	-.000 003	.000 426
4	.981	.027 9	131.	91.8	-.000 004	.000 419

21 FEET—6.401 METERS

Circular mils or A. W. G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.981	.002 24	8.76	75.1	.000 000	.000 505
600 000	.981	.002 40	9.44	75.6	.000 000	.000 502
550 000	.981	.002 59	10.3	76.1	.000 000	.000 498
500 000	.981	.002 81	11.2	76.7	.000 000	.000 495
450 000	.981	.003 09	12.4	77.3	-.000 001	.000 491
400 000	.981	.003 43	13.9	78.2	-.000 001	.000 486
350 000	.981	.003 86	15.8	78.9	-.000 001	.000 481
300 000	.981	.004 44	18.4	79.8	-.000 001	.000 476
250 000	.981	.005 25	22.1	80.8	-.000 001	.000 469
0 000	.981	.006 10	26.0	82.5	-.000 001	.000 463
000	.981	.007 56	32.8	[illegible]3.8	-.000 001	.000 455
00	.981	.009 36	41.3	85.2	-.000 001	.000 447
0	.981	.011 6	52.0	86.6	-.000 002	.000 441
1	.981	.014 4	65.6	88.0	-.000 002	.000 433
2	.981	.017 9	82.7	89.5	-.000 003	.000 427
3	.981	.022 2	104.	91.1	-.000 003	.000 420
4	.981	.027 6	131.	92.9	-.000 004	.000 414

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}010} + \frac{Z^4Y^4}{362{,}880} - \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

95 MILES—152.89 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

5 FEET—1.524 METERS

CIRCULAR MILS OR A. W. G. (B. & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G BASED UPON COPPER 97% ALUMIN. 61%	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 69	7.51	52.2	−.000 001	.000 708
1 113 000	700 000	.981	.002 86	8.04	52.5	−.000 001	.000 702
1 033 500	650 000	.981	.003 05	8.65	52.9	−.000 001	.000 697
954 000	600 000	.981	.003 27	9.35	53.4	−.000 001	.000 690
874 500	550 000	.981	.003 54	10.2	53.8	−.000 001	.000 685
795 000	500 000	.981	.003 83	11.2	54.4	−.000 001	.000 677
715 500	450 000	.981	.004 23	12.5	55.0	−.000 001	.000 669
636 000	400 000	.981	.004 68	14.0	55.6	−.000 001	.000 662
556 500	350 000	.981	.005 25	15.8	55.9	−.000 001	.000 658
477 000	300 000	.981	.006 03	18.4	56.9	−.000 001	.000 648
397 500	250 000	.981	.007 10	22.1	58.0	−.000 002	.000 636
336 400	0 000	.981	.008 26	26.1	59.0	−.000 002	.000 626
266 800	000	.981	.010 1	32.8	60.9	−.000 002	.000 606
0 000	00	.979	.013 1	43.5	69.9	−.000 003	.000 593
000	0	.979	.016 0	54.3	71.0	−.000 003	.000 580
00	1	.979	.019 4	67.3	72.2	−.000 004	.000 569
0	2	.979	.023 6	83.7	73.3	−.000 004	.000 557
1	3	.980	.029 1	105.	74.8	−.000 005	.000 546
2	4	.980	.035 8	132.	76.3	−.000 006	.000 535

7 FEET—2.134 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 51	7.51	56.0	−.000 001	.000 659
1 113 000	700 000	.981	.002 66	8.04	56.4	−.000 001	.000 654
1 033 500	650 000	.981	.002 84	8.65	56.8	−.000 001	.000 649
954 000	600 000	.981	.003 05	9.35	57.2	−.000 001	.000 644
874 500	550 000	.981	.003 30	10.2	57.7	−.000 001	.000 638
795 000	500 000	.981	.003 57	11.2	58.2	−.000 001	.000 632
715 500	450 000	.981	.003 95	12.5	58.8	−.000 001	.000 625
636 000	400 000	.981	.004 38	14.0	59.5	−.000 001	.000 618
556 500	350 000	.981	.004 91	15.8	59.8	−.000 001	.000 616
477 000	300 000	.981	.005 64	18.4	60.7	−.000 001	.000 606
397 500	250 000	.981	.006 65	22.1	61.9	−.000 001	.000 596
336 400	0 000	.981	.007 75	26.1	62.9	−.000 002	.000 587
266 800	000	.981	.009 48	32.8	64.7	−.000 002	.000 570
0 000	00	.979	.012 3	43.5	73.8	−.000 002	.000 559
000	0	.979	.015 1	54.3	74.8	−.000 003	.000 547
00	1	.979	.018 3	67.3	75.9	−.000 003	.000 537
0	2	.980	.022 3	83.7	77.2	−.000 004	.000 527
1	3	.980	.027 5	105.	78.5	−.000 005	.000 516
2	4	.980	.033 9	132.	80.1	−.000 006	.000 507

9 FEET—2.743 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 38	7.51	58.9	−.000 001	.000 626
1 113 000	700 000	.981	.002 53	8.04	59.2	−.000 001	.000 622
1 033 500	650 000	.981	.002 70	8.65	59.7	−.000 001	.000 617
954 000	600 000	.981	.002 90	9.35	60.2	−.000 001	.000 613
874 500	550 000	.981	.003 14	10.2	60.5	−.000 001	.000 607
795 000	500 000	.981	.003 40	11.2	61.1	−.000 001	.000 602
715 500	450 000	.981	.003 76	12.5	61.7	−.000 001	.000 596
636 000	400 000	.981	.004 17	14.0	62.4	−.000 001	.000 589
556 500	350 000	.981	.004 69	15.8	62.7	−.000 001	.000 587
477 000	300 000	.981	.005 39	18.4	63.6	−.000 001	.000 579
397 500	250 000	.981	.006 35	22.1	64.7	−.000 001	.000 569
336 400	0 000	.981	.007 40	26.1	65.8	−.000 001	.000 561
266 800	000	.981	.009 07	32.8	67.6	−.000 002	.000 546
0 000	00	.979	.011 8	43.5	76.6	−.000 002	.000 535
000	0	.979	.014 4	54.3	77.6	−.000 003	.000 525
00	1	.980	.017 6	67.3	78.8	−.000 003	.000 515
0	2	.980	.021 4	83.7	80.1	−.000 004	.000 505
1	3	.980	.026 4	105.	81.4	−.000 004	.000 496
2	4	.980	.032 6	132.	82.9	−.000 005	.000 487

11 FEET—3.353 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 29	7.51	61.2	.000 000	.000 602
1 113 000	700 000	.981	.002 44	8.04	61.6	.000 000	.000 599
1 033 500	650 000	.981	.002 60	8.65	61.9	−.000 001	.000 594
954 000	600 000	.981	.002 79	9.35	62.4	−.000 001	.000 590
874 500	550 000	.981	.003 03	10.2	62.9	−.000 001	.000 584
795 000	500 000	.981	.003 28	11.2	63.4	−.000 001	.000 580
715 500	450 000	.981	.003 63	12.5	64.0	−.000 001	.000 575
636 000	400 000	.981	.004 02	14.0	64.7	−.000 001	.000 568
556 500	350 000	.981	.004 51	15.8	65.0	−.000 001	.000 566
477 000	300 000	.981	.005 19	18.4	65.9	−.000 001	.000 558
397 500	250 000	.981	.006 13	22.1	67.1	−.000 001	.000 550
336 400	0 000	.981	.007 16	26.1	68.0	−.000 001	.000 542
266 800	000	.981	.008 76	32.8	69.9	−.000 002	.000 527
0 000	00	.979	.011 4	43.5	79.0	−.000 002	.000 517
000	0	.980	.014 0	54.3	80.0	−.000 002	.000 508
00	1	.980	.017 0	67.3	81.1	−.000 003	.000 498
0	2	.980	.020 8	83.7	82.3	−.000 003	.000 490
1	3	.980	.025 6	105.	83.7	−.000 004	.000 481
2	4	.980	.031 7	132.	85.2	−.000 005	.000 473

13 FEET—3.962 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 22	7.51	63.1	.000 000	.000 584
1 113 000	700 000	.981	.002 36	8.04	63.5	.000 000	.000 581
1 033 500	650 000	.981	.002 52	8.65	63.8	.000 000	.000 576
954 000	600 000	.981	.002 71	9.35	64.3	−.000 001	.000 572
874 500	550 000	.981	.002 94	10.2	64.8	−.000 001	.000 567
795 000	500 000	.981	.003 18	11.2	65.3	−.000 001	.000 563
715 500	450 000	.981	.003 52	12.5	65.9	−.000 001	.000 557
636 000	400 000	.981	.003 90	14.0	66.6	−.000 001	.000 551
556 500	350 000	.981	.004 38	15.8	66.9	−.000 001	.000 550
477 000	300 000	.981	.005 05	18.4	67.8	−.000 001	.000 543
397 500	250 000	.981	.005 96	22.1	69.0	−.000 001	.000 534
336 400	0 000	.981	.006 96	26.1	69.9	−.000 001	.000 527
266 800	000	.981	.008 54	32.8	71.8	−.000 001	.000 514
0 000	00	.979	.011 1	43.5	80.8	−.000 002	.000 504
000	0	.980	.013 6	54.3	81.9	−.000 002	.000 494
00	1	.980	.016 6	67.3	83.0	−.000 003	.000 486
0	2	.980	.020 3	83.7	84.2	−.000 003	.000 478
1	3	.980	.025 0	105.	85.6	−.000 004	.000 469
2	4	.980	.030 9	132.	87.1	−.000 005	.000 462

15 FEET—4.572 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 16	7.51	64.8	.000 000	.000 568
1 113 000	700 000	.981	.002 30	8.04	65.2	.000 000	.000 566
1 033 500	650 000	.981	.002 46	8.65	65.5	.000 000	.000 562
954 000	600 000	.981	.002 64	9.35	66.0	.000 000	.000 558
874 500	550 000	.981	.002 86	10.2	66.4	−.000 001	.000 553
795 000	500 000	.981	.003 10	11.2	67.0	−.000 001	.000 549
715 500	450 000	.981	.003 44	12.5	67.6	−.000 001	.000 544
636 000	400 000	.981	.003 81	14.0	68.3	−.000 001	.000 538
556 500	350 000	.981	.004 28	15.8	68.6	−.000 001	.000 536
477 000	300 000	.981	.004 93	18.4	69.4	−.000 001	.000 530
397 500	250 000	.981	.005 82	22.1	70.6	−.000 001	.000 521
336 400	0 000	.981	.006 79	26.1	71.6	−.000 001	.000 515
266 800	000	.981	.008 34	32.8	73.5	−.000 001	.000 501
0 000	00	.980	.010 9	43.5	82.4	−.000 002	.000 493
000	0	.980	.013 3	54.3	83.6	−.000 002	.000 484
00	1	.980	.016 2	67.3	84.6	−.000 003	.000 476
0	2	.980	.019 8	83.7	85.9	−.000 003	.000 467
1	3	.980	.024 4	105.	87.2	−.000 004	.000 460
2	4	.980	.030 3	132.	88.7	−.000 005	.000 452

17 FEET—5.182 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 12	7.51	66.2	.000 000	.000 556
1 113 000	700 000	.981	.002 25	8.04	66.6	.000 000	.000 553
1 033 500	650 000	.981	.002 41	8.65	67.0	.000 000	.000 550
954 000	600 000	.981	.002 58	9.35	67.4	.000 000	.000 546
874 500	550 000	.981	.002 81	10.2	67.9	−.000 001	.000 542
795 000	500 000	.981	.003 04	11.2	68.4	−.000 001	.000 537
715 500	450 000	.981	.003 36	12.5	69.0	−.000 001	.000 533
636 000	400 000	.981	.003 74	14.0	69.7	−.000 001	.000 528
556 500	350 000	.981	.004 19	15.8	70.0	−.000 001	.000 525
477 000	300 000	.981	.004 83	18.4	70.8	−.000 001	.000 518
397 500	250 000	.981	.005 70	22.1	72.0	−.000 001	.000 511
336 400	0 000	.981	.006 66	26.1	73.0	−.000 001	.000 504
266 800	000	.981	.008 18	32.8	74.9	−.000 001	.000 492
0 000	00	.980	.010 7	43.5	83.9	−.000 002	.000 483
000	0	.980	.013 1	54.3	85.0	−.000 002	.000 475
00	1	.980	.015 9	67.3	86.0	−.000 003	.000 467
0	2	.980	.019 5	83.7	87.3	−.000 003	.000 459
1	3	.980	.024 0	105.	88.6	−.000 004	.000 451
2	4	.980	.029 8	132.	90.1	−.000 004	.000 445

19 FEET—5.791 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 08	7.51	67.4	.000 000	.000 546
1 113 000	700 000	.981	.002 21	8.04	67.8	.000 000	.000 543
1 033 500	650 000	.981	.002 36	8.65	68.2	.000 000	.000 539
954 000	600 000	.981	.002 54	9.35	68.7	.000 000	.000 535
874 500	550 000	.981	.002 75	10.2	69.1	.000 000	.000 532
795 000	500 000	.981	.002 98	11.2	69.7	−.000 001	.000 528
715 500	450 000	.981	.003 30	12.5	70.3	−.000 001	.000 523
636 000	400 000	.981	.003 67	14.0	70.9	−.000 001	.000 518
556 500	350 000	.981	.004 11	15.8	71.2	−.000 001	.000 516
477 000	300 000	.981	.004 74	18.4	72.2	−.000 001	.000 510
397 500	250 000	.981	.005 61	22.1	73.3	−.000 001	.000 502
336 400	0 000	.981	.006 55	26.1	74.3	−.000 001	.000 496
266 800	000	.981	.008 04	32.8	76.2	−.000 001	.000 483
0 000	00	.980	.010 5	43.5	85.2	−.000 002	.000 475
000	0	.980	.012 9	54.3	86.2	−.000 002	.000 467
00	1	.980	.015 7	67.3	87.4	−.000 002	.000 460
0	2	.980	.019 1	83.7	88.5	−.000 003	.000 451
1	3	.980	.023 6	105.	89.9	−.000 004	.000 445
2	4	.980	.029 3	132.	91.3	−.000 004	.000 437

21 FEET—6.401 METERS

CIRCULAR MILS	COPPER EQUIVALENT	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 192 500	750 000	.981	.002 04	7.51	68.7	.000 000	.000 536
1 113 000	700 000	.981	.002 17	8.04	68.9	.000 000	.000 533
1 033 500	650 000	.981	.002 32	8.65	69.3	.000 000	.000 530
954 000	600 000	.981	.002 49	9.35	69.8	.000 000	.000 527
874 500	550 000	.981	.002 71	10.2	70.3	.000 000	.000 523
795 000	500 000	.981	.002 93	11.2	70.8	−.000 001	.000 518
715 500	450 000	.981	.003 25	12.5	71.4	−.000 001	.000 515
636 000	400 000	.981	.003 61	14.0	72.1	−.000 001	.000 510
556 500	350 000	.981	.004 05	15.8	72.3	−.000 001	.000 508
477 000	300 000	.981	.004 67	18.4	73.3	−.000 001	.000 501
397 500	250 000	.981	.005 52	22.1	74.4	−.000 001	.000 495
336 400	0 000	.981	.006 44	26.1	75.5	−.000 001	.000 488
266 800	000	.981	.007 91	32.8	77.3	−.000 001	.000 476
0 000	00	.980	.010 3	43.5	86.3	−.000 002	.000 468
000	0	.980	.012 7	54.3	87.3	−.000 002	.000 460
00	1	.980	.015 4	67.3	88.5	−.000 002	.000 453
0	2	.980	.018 9	83.7	89.6	−.000 003	.000 445
1	3	.980	.023 3	105.	91.1	−.000 003	.000 439
2	4	.980	.028 9	132.	92.5	−.000 004	.000 431

$$A=\cosh\theta=\left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40,320}+\right)\qquad B=Z\frac{\sinh\theta}{\theta}=Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5,040}+\frac{Z^4Y^4}{362,880}+\right)\qquad C=Y\frac{\sinh\theta}{\theta}=Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5,040}+\frac{Z^4Y^4}{362,880}+\right)$$

in which Z is the total impedance $(rl+jxl)$ in ohms and Y is the total admittance $o+jbl\times10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D=\sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

100 MILES—160.94 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S.)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.979	.00301	9.21	65.7	-.000001	.000644	.979	.00287	9.21	68.8	-.000001	.000615	.979	.00277	9.21	71.2	-.000001	.000593
600 000	.979	.00321	9.93	66.3	-.000001	.000638	.979	.00307	9.93	69.3	-.000001	.000610	.979	.00296	9.93	71.8	-.000001	.000588
550 000	.979	.00346	10.8	66.8	-.000001	.000633	.979	.00330	10.8	69.9	-.000001	.000605	.979	.00319	10.8	72.3	-.000001	.000584
500 000	.979	.00376	11.8	67.4	-.000001	.000628	.979	.00359	11.8	70.4	-.000001	.000600	.979	.00346	11.8	72.9	-.000001	.000579
450 000	.979	.00411	13.1	68.0	-.000001	.000622	.979	.00393	13.1	71.1	-.000001	.000594	.979	.00380	13.1	73.5	-.000001	.000574
400 000	.979	.00456	14.6	68.9	-.000001	.000615	.979	.00436	14.6	72.0	-.000001	.000588	.979	.00421	14.6	74.4	-.000001	.000568
350 000	.979	.00513	16.7	69.7	-.000001	.000608	.979	.00491	16.7	72.8	-.000001	.000581	.979	.00474	16.7	75.2	-.000001	.000561
300 000	.979	.00588	19.4	70.7	-.000001	.000599	.979	.00563	19.4	73.7	-.000001	.000573	.979	.00545	19.4	76.2	-.000001	.000554
250 000	.979	.00693	23.2	71.8	-.000001	.000589	.979	.00664	23.2	74.8	-.000001	.000564	.979	.00643	23.2	77.3	-.000001	.000546
0000	.979	.00805	27.4	73.5	-.000002	.000580	.979	.00770	27.4	76.5	-.000001	.000555	.979	.00746	27.4	79.0	-.000001	.000537
000	.979	.00992	34.5	75.0	-.000002	.000568	.979	.00953	34.5	78.0	-.000002	.000545	.979	.00921	34.5	80.4	-.000002	.000527
00	.979	.0123	43.4	76.4	-.000002	.000557	.979	.0118	43.4	79.4	-.000002	.000535	.979	.0114	43.4	81.9	-.000002	.000518
0	.979	.0152	54.7	77.9	-.000003	.000547	.979	.0146	54.7	80.9	-.000003	.000525	.979	.0141	54.7	83.4	-.000002	.000509
1	.979	.0187	68.9	79.5	-.000003	.000536	.979	.0180	68.9	82.4	-.000003	.000515	.979	.0175	68.9	84.9	-.000003	.000500
2	.979	.0232	86.9	81.1	-.000004	.000526	.979	.0223	86.9	84.2	-.000004	.000506	.979	.0217	86.9	86.5	-.000004	.000491

	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.979	.00269	9.21	73.2	-.000001	.000575	.979	.00262	9.21	75.0	.000000	.000562	.979	.00257	9.21	76.5	.000000	.000550
600 000	.979	.00287	9.93	73.8	-.000001	.000571	.979	.00281	9.93	75.5	-.000001	.000558	.979	.00275	9.93	77.0	-.000001	.000546
550 000	.979	.00310	10.8	74.3	-.000001	.000567	.979	.00303	10.8	76.1	-.000001	.000554	.979	.00296	10.8	77.6	-.000001	.000542
500 000	.979	.00337	11.8	74.9	-.000001	.000563	.979	.00329	11.8	76.6	-.000001	.000549	.979	.00322	11.8	78.1	-.000001	.000538
450 000	.979	.00369	13.1	75.5	-.000001	.000558	.979	.00361	13.1	77.3	-.000001	.000545	.979	.00354	13.1	78.8	-.000001	.000534
400 000	.979	.00410	14.6	76.4	-.000001	.000552	.979	.00400	14.6	78.2	-.000001	.000539	.979	.00392	14.6	79.6	-.000001	.000528
350 000	.979	.00461	16.7	77.3	-.000001	.000546	.979	.00450	16.7	79.0	-.000001	.000533	.979	.00442	16.7	80.4	-.000001	.000523
300 000	.979	.00530	19.4	78.2	-.000001	.000539	.979	.00518	19.4	79.9	-.000001	.000527	.979	.00507	19.4	81.4	-.000001	.000516
250 000	.979	.00625	23.2	79.3	-.000001	.000531	.979	.00611	23.2	81.0	-.000001	.000519	.979	.00600	23.2	82.6	-.000001	.000509
0000	.979	.00726	27.4	81.0	-.000001	.000523	.979	.00711	27.4	82.7	-.000001	.000512	.979	.00697	27.4	84.2	-.000001	.000502
000	.979	.00898	34.5	82.4	-.000002	.000514	.979	.00880	34.5	84.1	-.000001	.000503	.979	.00862	34.5	85.6	-.000001	.000493
00	.979	.0111	43.4	83.9	-.000002	.000505	.979	.0109	43.4	85.5	-.000002	.000494	.979	.0107	43.4	87.0	-.000002	.000486
0	.979	.0138	54.7	85.3	-.000002	.000496	.979	.0135	54.7	87.0	-.000002	.000487	.979	.0132	54.7	88.6	-.000002	.000478
1	.979	.0171	68.9	86.9	-.000003	.000489	.979	.0167	68.9	88.6	-.000003	.000478	.979	.0164	68.9	90.1	-.000003	.000470
2	.979	.0211	86.9	88.5	-.000003	.000480	.979	.0207	86.9	90.2	-.000003	.000471	.979	.0204	86.9	91.7	-.000003	.000462

	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.979	.00252	9.21	77.8	.000000	.000540	.979	.00248	9.21	78.9	.000000	.000531	.979	.00245	9.21	80.0	.000000	.000524
600 000	.979	.00270	9.93	78.3	.000000	.000536	.979	.00266	9.93	79.5	.000000	.000528	.979	.00262	9.93	80.6	.000000	.000520
550 000	.979	.00291	10.8	78.8	-.000001	.000533	.979	.00286	10.8	80.0	-.000001	.000524	.979	.00283	10.8	81.1	.000000	.000517
500 000	.979	.00317	11.8	79.4	-.000001	.000529	.979	.00311	11.8	80.6	-.000001	.000520	.979	.00307	11.8	81.7	-.000001	.000513
450 000	.979	.00347	13.1	80.0	-.000001	.000524	.979	.00342	13.1	81.3	-.000001	.000516	.979	.00337	13.1	82.4	-.000001	.000509
400 000	.979	.00385	14.6	81.0	-.000001	.000519	.979	.00379	14.6	82.2	-.000001	.000511	.979	.00374	14.6	83.3	-.000001	.000504
350 000	.979	.00435	16.7	81.8	-.000001	.000514	.979	.00428	16.7	83.0	-.000001	.000506	.979	.00422	16.7	84.1	-.000001	.000499
300 000	.979	.00500	19.4	82.7	-.000001	.000508	.979	.00492	19.4	83.9	-.000001	.000500	.979	.00485	19.4	85.0	-.000001	.000493
250 000	.979	.00590	23.2	83.8	-.000001	.000501	.979	.00581	23.2	85.0	-.000001	.000493	.979	.00574	23.2	86.1	-.000001	.000488
0000	.979	.00686	27.4	85.6	-.000001	.000494	.979	.00675	27.4	86.7	-.000001	.000487	.979	.00667	27.4	87.8	-.000001	.000481
000	.979	.00848	34.5	87.0	-.000001	.000486	.979	.00836	34.5	88.2	-.000001	.000479	.979	.00826	34.5	89.3	-.000001	.000473
00	.979	.0105	43.4	88.4	-.000002	.000478	.979	.0104	43.4	89.6	-.000002	.000471	.979	.0102	43.4	90.7	-.000002	.000465
0	.979	.0130	54.7	89.9	-.000002	.000470	.979	.0129	54.7	91.1	-.000002	.000464	.979	.0127	54.7	92.2	-.000002	.000458
1	.979	.0162	68.9	91.4	-.000003	.000463	.979	.0159	68.9	92.6	-.000002	.000456	.979	.0158	68.9	93.7	-.000002	.000451
2	.979	.0200	86.9	93.0	-.000003	.000455	.979	.0198	86.9	94.2	-.000003	.000449	.979	.0196	86.9	95.3	-.000003	.000444

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI. l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

100 MILES—160.94 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT† CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.979	.00249	6.99	58.2	-.000001	.000702	.979	.00236	6.99	61.2	-.000001	.000666	.979	.00227	6.99	63.7	.000000	.000641
1 272 000	800 000	.979	.00262	7.42	58.6	-.000001	.000697	.979	.00249	7.42	61.6	-.000001	.000662	.979	.00240	7.42	64.0	-.000001	.000638
1 192 500	750 000	.979	.00278	7.90	58.9	-.000001	.000693	.979	.00264	7.90	62.0	-.000001	.000658	.979	.00254	7.90	64.4	-.000001	.000634
1 113 000	700 000	.979	.00295	8.45	59.3	-.000001	.000688	.979	.00280	8.45	62.3	-.000001	.000655	.979	.00270	8.45	64.8	-.000001	.000630
1 033 500	650 000	.979	.00315	9.09	59.7	-.000001	.000682	.979	.00299	9.09	62.8	-.000001	.000650	.979	.00288	9.09	65.2	-.000001	.000625
954 000	600 000	.979	.00338	9.83	60.2	-.000001	.000677	.979	.00321	9.83	63.3	-.000001	.000645	.979	.00309	9.83	65.7	-.000001	.000621
874 500	550 000	.979	.00366	10.8	60.7	-.000001	.000671	.979	.00348	10.8	63.7	-.000001	.000639	.979	.00335	10.8	66.2	-.000001	.000615
795 000	500 000	.979	.00395	11.7	61.2	-.000001	.000664	.979	.00377	11.7	64.3	-.000001	.000634	.979	.00363	11.7	66.7	-.000001	.000610
715 500	450 000	.979	.00437	13.1	61.9	-.000001	.000657	.979	.00417	13.1	64.9	-.000001	.000627	.979	.00402	13.1	67.4	-.000001	.000605
636 000	400 000	.979	.00485	14.7	62.6	-.000001	.000651	.979	.00462	14.7	65.7	-.000001	.000620	.979	.00445	14.7	68.1	-.000001	.000598
556 500	350 000	.979	.00544	16.6	62.9	-.000001	.000648	.979	.00519	16.6	66.0	-.000001	.000618	.979	.00500	16.6	68.4	-.000001	.000595
477 000	300 000	.979	.00625	19.3	63.8	-.000001	.000638	.979	.00596	19.3	66.9	-.000001	.000609	.979	.00575	19.3	69.4	-.000001	.000587
397 500	250 000	.979	.00736	23.2	65.1	-.000002	.000627	.979	.00704	23.2	68.1	-.000001	.000599	.979	.00679	23.2	70.6	-.000001	.000578
336 400	0 000	.979	.00858	27.4	66.1	-.000002	.000618	.979	.00820	27.4	69.2	-.000002	.000590	.979	.00792	27.4	71.6	-.000002	.000570
266 800	000	.979	.0105	34.5	68.1	-.000002	.000600	.979	.0100	34.5	71.1	-.000002	.000574	.979	.00970	34.5	73.5	-.000002	.000554
0 000	00	.977	.0136	45.7	77.6	-.000003	.000588	.977	.0131	45.7	80.6	-.000002	.000563	.977	.0126	45.7	83.1	-.000002	.000544
000	0	.977	.0167	57.0	78.7	-.000003	.000576	.977	.0160	57.0	81.7	-.000003	.000552	.977	.0155	57.0	84.2	-.000003	.000534
00	1	.977	.0203	70.7	79.9	-.000004	.000565	.977	.0195	70.7	83.0	-.000004	.000542	.977	.0188	70.7	85.3	-.000003	.000524
0	2	.977	.0247	88.0	81.2	-.000005	.000554	.977	.0237	88.0	84.3	-.000004	.000531	.978	.0230	88.0	86.6	-.000004	.000515

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.979	.00220	6.99	65.7	.000000	.000621	.979	.00214	6.99	67.4	.000000	.000605	.979	.00210	6.99	68.9	.000000	.000592
1 272 000	800 000	.979	.00232	7.42	66.1	.000000	.000618	.979	.00226	7.42	67.7	.000000	.000602	.979	.00221	7.42	69.3	.000000	.000589
1 192 500	750 000	.979	.00246	7.90	66.4	-.000001	.000614	.979	.00239	7.90	68.1	.000000	.000598	.979	.00234	7.90	69.6	.000000	.000585
1 113 000	700 000	.979	.00262	8.45	66.8	-.000001	.000611	.979	.00255	8.45	68.5	-.000001	.000595	.979	.00249	8.45	70.0	.000000	.000582
1 033 500	650 000	.979	.00279	9.09	67.1	-.000001	.000606	.979	.00272	9.09	68.9	-.000001	.000591	.979	.00266	9.09	70.4	-.000001	.000578
954 000	600 000	.979	.00300	9.83	67.6	-.000001	.000602	.979	.00293	9.83	69.4	-.000001	.000587	.979	.00286	9.83	70.9	-.000001	.000574
874 500	550 000	.979	.00325	10.8	68.1	-.000001	.000597	.979	.00317	10.8	69.8	-.000001	.000582	.979	.00311	10.8	71.4	-.000001	.000570
795 000	500 000	.979	.00352	11.7	68.7	-.000001	.000592	.979	.00343	11.7	70.4	-.000001	.000577	.979	.00336	11.7	71.9	-.000001	.000565
715 500	450 000	.979	.00390	13.1	69.3	-.000001	.000586	.979	.00380	13.1	71.1	-.000001	.000572	.979	.00372	13.1	72.6	-.000001	.000560
636 000	400 000	.979	.00432	14.7	70.0	-.000001	.000580	.979	.00422	14.7	71.8	-.000001	.000566	.979	.00414	14.7	73.3	-.000001	.000555
556 500	350 000	.979	.00486	16.6	70.3	-.000001	.000578	.979	.00474	16.6	72.1	-.000001	.000564	.979	.00464	16.6	73.6	-.000001	.000552
477 000	300 000	.979	.00560	19.3	71.3	-.000001	.000571	.979	.00546	19.3	73.0	-.000001	.000557	.979	.00534	19.3	74.5	-.000001	.000545
397 500	250 000	.979	.00660	23.2	72.6	-.000001	.000562	.979	.00644	23.2	74.2	-.000001	.000548	.979	.00631	23.2	75.7	-.000001	.000537
336 400	0 000	.979	.00770	27.4	73.6	-.000001	.000554	.979	.00752	27.4	75.4	-.000001	.000541	.979	.00737	27.4	76.8	-.000001	.000530
226 800	000	.979	.00945	34.5	75.6	-.000002	.000540	.979	.00923	34.5	77.3	-.000002	.000527	.979	.00906	34.5	78.8	-.000002	.000517
0 000	00	.977	.0123	45.7	85.0	-.000002	.000530	.977	.0120	45.7	86.7	-.000002	.000518	.977	.0118	45.7	88.3	-.000002	.000508
000	0	.977	.0151	57.0	86.1	-.000003	.000520	.977	.0147	57.0	87.9	-.000003	.000509	.977	.0145	57.0	89.4	-.000002	.000499
00	1	.978	.0184	70.7	87.4	-.000003	.000511	.978	.0180	70.7	89.1	-.000003	.000500	.978	.0176	70.7	90.5	-.000003	.000491
0	2	.978	.0224	88.0	88.6	-.000004	.000502	.978	.0219	88.0	90.4	-.000004	.000491	.978	.0215	88.0	91.9	-.000004	.000482

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.979	.00206	6.99	70.2	.000000	.000580	.979	.00202	6.99	71.4	.000000	.000570	.979	.00199	6.99	72.5	.000000	.000562
1 272 000	800 000	.979	.00217	7.42	70.6	.000000	.000577	.979	.00214	7.42	71.8	.000000	.000568	.979	.00210	7.42	72.9	.000000	.000559
1 192 500	750 000	.979	.00230	7.90	70.9	.000000	.000574	.979	.00226	7.90	72.2	.000000	.000564	.979	.00223	7.90	73.3	.000000	.000556
1 113 000	700 000	.979	.00245	8.45	71.3	.000000	.000571	.979	.00240	8.45	72.5	.000000	.000561	.979	.00237	8.45	73.6	.000000	.000553
1 033 500	650 000	.979	.00261	9.09	71.7	.000000	.000567	.979	.00257	9.09	72.9	.000000	.000557	.979	.00253	9.09	74.0	.000000	.000549
954 000	600 000	.979	.00281	9.83	72.2	-.000001	.000563	.979	.00276	9.83	73.4	-.000001	.000554	.979	.00272	9.83	74.6	-.000001	.000546
874 500	550 000	.979	.00305	10.8	72.7	-.000001	.000559	.979	.00300	10.8	73.9	-.000001	.000550	.979	.00296	10.8	75.0	-.000001	.000542
795 000	500 000	.979	.00330	11.7	73.3	-.000001	.000555	.979	.00324	11.7	74.5	-.000001	.000545	.979	.00320	11.7	75.6	-.000001	.000537
715 500	450 000	.979	.00366	13.1	73.9	-.000001	.000550	.979	.00360	13.1	75.1	-.000001	.000541	.979	.00355	13.1	76.2	-.000001	.000533
636 000	400 000	.979	.00406	14.7	74.6	-.000001	.000545	.979	.00400	14.7	75.8	-.000001	.000536	.979	.00394	14.7	76.9	-.000001	.000528
556 500	350 000	.979	.00455	16.6	74.9	-.000001	.000542	.979	.00449	16.6	76.1	-.000001	.000534	.979	.00442	16.6	77.2	-.000001	.000526
477 000	300 000	.979	.00525	19.3	75.9	-.000001	.000536	.979	.00510	19.3	77.1	-.000001	.000527	.979	.00510	19.3	78.2	-.000001	.000520
397 500	250 000	.979	.00621	23.2	77.1	-.000001	.000528	.979	.00611	23.2	78.3	-.000001	.000520	.979	.00602	23.2	79.4	-.000001	.000512
336 400	0 000	.979	.00725	27.4	78.1	-.000001	.000521	.979	.00714	27.4	79.4	-.000001	.000513	.979	.00704	27.4	80.4	-.000001	.000507
266 800	000	.979	.00890	34.5	80.1	-.000002	.000509	.979	.00876	34.5	81.3	-.000001	.000501	.979	.00865	34.5	82.4	-.000001	.000495
0 000	00	.977	.0116	45.7	89.6	-.000002	.000499	.977	.0114	45.7	90.8	-.000002	.000492	.977	.0113	45.7	91.9	-.000002	.000485
000	0	.977	.0142	57.0	90.7	-.000002	.000491	.977	.0140	57.0	91.9	-.000002	.000484	.977	.0138	57.0	93.0	-.000002	.000477
00	1	.978	.0174	70.7	91.9	-.000003	.000483	.978	.0171	70.7	93.1	-.000003	.000476	.978	.0169	70.7	94.2	-.000003	.000471
0	2	.978	.0212	88.0	93.1	-.000003	.000475	.978	.0209	88.0	94.3	-.000003	.000469	.978	.0207	88.0	95.4	-.000003	.000463

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

110 MILES—177.03 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.974	.003 64	10.1	72.2	-.000 001	.000 708	.974	.003 47	10.1	75.6	-.000 001	.000 675	.974	.003 35	10.1	78.2	-.000 001	.000 651
600 000	.974	.003 89	10.9	72.9	-.000 001	.000 702	.974	.003 71	10.9	76.2	-.000 001	.000 670	.974	.003 58	10.9	78.9	-.000 001	.000 646
550 000	.974	.004 18	11.8	73.4	-.000 001	.000 696	.974	.003 99	11.8	76.8	-.000 001	.000 664	.974	.003 86	11.8	79.4	-.000 001	.000 642
500 000	.974	.004 54	12.9	74.1	-.000 001	.000 690	.974	.004 34	12.9	77.4	-.000 001	.000 659	.974	.004 19	12.9	80.1	-.000 001	.000 636
450 000	.974	.004 97	14.3	74.8	-.000 001	.000 683	.974	.004 75	14.3	78.1	-.000 001	.000 652	.974	.004 59	14.3	80.8	-.000 001	.000 631
400 000	.974	.005 51	16.0	75.7	-.000 001	.000 675	.974	.005 27	16.0	79.1	-.000 001	.000 646	.974	.005 09	16.0	81.7	-.000 001	.000 624
350 000	.974	.006 20	18.3	76.6	-.000 001	.000 668	.974	.005 93	18.3	80.0	-.000 001	.000 638	.974	.005 73	18.3	82.6	-.000 001	.000 616
300 000	.974	.007 11	21.3	77.7	-.000 002	.000 658	.974	.006 80	21.3	81.0	-.000 001	.000 630	.974	.006 58	21.3	83.7	-.000 001	.000 609
250 000	.974	.008 38	25.4	79.0	-.000 002	.000 647	.974	.008 02	25.4	82.2	-.000 002	.000 620	.974	.007 77	25.4	84.9	-.000 002	.000 600
0 000	.974	.009 73	30.0	80.8	-.000 002	.000 637	.974	.009 31	30.0	84.1	-.000 002	.000 610	.974	.009 01	30.0	86.8	-.000 002	.000 590
000	.974	.012 0	37.8	82.4	-.000 003	.000 624	.974	.011 5	37.8	85.7	-.000 002	.000 599	.974	.011 1	37.8	88.4	-.000 002	.000 579
00	.974	.014 8	47.6	84.0	-.000 003	.000 612	.974	.014 2	47.6	87.3	-.000 003	.000 588	.974	.013 8	47.6	90.0	-.000 003	.000 570
0	.974	.018 3	60.0	85.7	-.000 004	.000 601	.974	.017 6	60.0	88.9	-.000 003	.000 577	.974	.017 1	60.0	91.7	-.000 003	.000 560
1	.974	.022 7	75.6	86.4	-.000 005	.000 589	.974	.021 8	75.6	90.7	-.000 004	.000 566	.974	.021 2	75.6	93.4	-.000 004	.000 550
2	.974	.028 0	95.3	89.3	-.000 005	.000 578	.974	.027 0	95.3	92.6	-.000 005	.000 556	.974	.026 2	95.3	95.2	-.000 005	.000 540

CIRCULAR MILS OR A. W. G. (B. & S.)	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.974	.003 25	10.1	80.4	-.000 001	.000 632	.974	.003 17	10.1	82.4	-.000 001	.000 618	.974	.003 11	10.1	84.0	-.000 001	.000 604
600 000	.974	.003 47	10.9	81.1	-.000 001	.000 627	.974	.003 40	10.9	82.9	-.000 001	.000 613	.974	.003 32	10.9	84.6	-.000 001	.000 600
550 000	.974	.003 74	11.8	81.6	-.000 001	.000 623	.974	.003 66	11.8	83.6	-.000 001	.000 609	.974	.003 58	11.8	85.2	-.000 001	.000 596
500 000	.974	.004 07	12.9	82.3	-.000 001	.000 619	.974	.003 97	12.9	84.1	-.000 001	.000 603	.974	.003 89	12.9	85.8	-.000 001	.000 591
450 000	.974	.004 46	14.3	82.9	-.000 001	.000 613	.974	.004 36	14.3	84.9	-.000 001	.000 599	.974	.004 27	14.3	86.5	-.000 001	.000 587
400 000	.974	.004 95	16.0	83.9	-.000 001	.000 607	.974	.004 83	16.0	85.9	-.000 001	.000 592	.974	.004 74	16.0	87.5	-.000 001	.000 580
350 000	.974	.005 58	18.3	84.9	-.000 001	.000 600	.974	.005 45	18.3	86.8	-.000 001	.000 586	.974	.005 34	18.3	88.4	-.000 001	.000 575
300 000	.974	.006 41	21.3	85.9	-.000 001	.000 592	.974	.006 26	21.3	87.8	-.000 001	.000 579	.974	.006 13	21.3	89.4	-.000 001	.000 567
250 000	.974	.007 55	25.4	87.1	-.000 001	.000 584	.974	.007 39	25.4	89.0	-.000 001	.000 571	.974	.007 25	25.4	90.7	-.000 001	.000 560
0 000	.974	.008 78	30.0	89.0	-.000 002	.000 575	.974	.008 59	30.0	90.9	-.000 002	.000 563	.974	.008 43	30.0	92.5	-.000 002	.000 552
000	.974	.010 9	37.8	90.6	-.000 002	.000 565	.974	.010 6	37.8	92.4	-.000 002	.000 553	.974	.010 4	37.8	94.1	-.000 002	.000 542
00	.974	.013 4	47.6	92.2	-.000 003	.000 555	.974	.013 2	47.6	94.0	-.000 002	.000 543	.974	.012 9	47.6	95.7	-.000 002	.000 533
0	.974	.016 7	60.0	93.8	-.000 003	.000 546	.974	.016 3	60.0	95.7	-.000 003	.000 535	.974	.016 0	60.0	97.4	-.000 003	.000 525
1	.974	.020 7	75.6	95.6	-.000 004	.000 537	.974	.020 2	75.6	97.4	-.000 004	.000 525	.974	.019 9	75.6	99.1	-.000 003	.000 516
2	.974	.025 6	95.3	97.4	-.000 005	.000 527	.974	.025 1	95.3	99.2	-.000 004	.000 517	.974	.024 6	95.3	101.	-.000 004	.000 507

CIRCULAR MILS OR A. W. G. (B. & S.)	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.974	.003 05	10.1	85.4	-.000 001	.000 594	.974	.003 00	10.1	86.7	-.000 001	.000 584	.974	.002 96	10.1	87.9	-.000 001	.000 576
600 000	.974	.003 26	10.9	86.1	-.000 001	.000 589	.974	.003 21	10.9	87.4	-.000 001	.000 580	.974	.003 17	10.9	88.6	-.000 001	.000 572
550 000	.974	.003 52	11.8	86.6	-.000 001	.000 586	.974	.003 46	11.8	87.9	-.000 001	.000 576	.974	.003 42	11.8	89.1	-.000 001	.000 568
500 000	.974	.003 83	12.9	87.3	-.000 001	.000 582	.974	.003 76	12.9	88.6	-.000 001	.000 572	.974	.003 71	12.9	89.8	-.000 001	.000 564
450 000	.974	.004 19	14.3	88.0	-.000 001	.000 576	.974	.004 13	14.3	89.4	-.000 001	.000 567	.974	.004 08	14.3	90.6	-.000 001	.000 560
400 000	.974	.004 66	16.0	89.1	-.000 001	.000 571	.974	.004 59	16.0	90.4	-.000 001	.000 562	.974	.004 52	16.0	91.6	-.000 001	.000 554
350 000	.974	.005 25	18.3	89.9	-.000 001	.000 565	.974	.005 17	18.3	91.2	-.000 001	.000 556	.974	.005 10	18.3	92.4	-.000 001	.000 549
300 000	.974	.006 04	21.3	90.9	-.000 001	.000 559	.974	.005 95	21.3	92.2	-.000 001	.000 550	.974	.005 86	21.3	93.4	-.000 001	.000 542
250 000	.974	.007 13	25.4	92.1	-.000 001	.000 551	.974	.007 02	25.4	93.5	-.000 001	.000 542	.974	.006 94	25.4	94.7	-.000 001	.000 536
0 000	.974	.008 29	30.0	94.0	-.000 002	.000 543	.974	.008 16	30.0	95.3	-.000 001	.000 535	.974	.008 06	30.0	96.5	-.000 001	.000 528
000	.974	.010 3	37.8	95.6	-.000 002	.000 533	.974	.010 1	37.8	96.9	-.000 002	.000 526	.974	.009 98	37.8	98.1	-.000 002	.000 519
00	.974	.012 7	47.6	97.2	-.000 002	.000 525	.974	.012 5	47.6	98.5	-.000 002	.000 517	.974	.012 4	47.6	99.7	-.000 002	.000 511
0	.974	.015 8	60.0	98.8	-.000 003	.000 516	.974	.015 5	60.0	100.	-.000 003	.000 509	.974	.015 3	60.0	101.	-.000 003	.000 503
1	.974	.019 6	75.6	101.	-.000 003	.000 508	.974	.019 3	75.6	102.	-.000 003	.000 501	.974	.019 1	75.6	103.	-.000 003	.000 495
2	.974	.024 2	95.3	102.	-.000 004	.000 500	.974	.023 9	95.3	104.	-.000 004	.000 493	.974	.023 7	95.3	105.	-.000 004	.000 488

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

110 MILES—177.03 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A W G BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.975	.003 01	7.67	63.9	-.000 001	.000 771	.975	.002 85	7.67	67.2	-.000 001	.000 732	.975	.002 74	7.67	69.9	-.000 001	.000 704
1 272 000	800 000	.975	.003 17	8.14	64.4	-.000 001	.000 766	.975	.003 01	8.14	67.7	-.000 001	.000 728	.975	.002 90	8.14	70.3	-.000 001	.000 700
1 192 500	750 000	.975	.003 35	8.67	64.7	-.000 001	.000 762	.975	.003 19	8.67	68.1	-.000 001	.000 723	.975	.003 07	8.67	70.7	-.000 001	.000 696
1 113 000	700 000	.975	.003 56	9.27	65.1	-.000 001	.000 756	.975	.003 39	9.27	68.4	-.000 001	.000 719	.975	.003 26	9.27	71.1	-.000 001	.000 692
1 033 500	650 000	.975	.003 80	9.98	65.6	-.000 001	.000 750	.975	.003 62	9.98	69.0	-.000 001	.000 714	.975	.003 48	9.98	71.6	-.000 001	.000 686
954 000	600 000	.975	.004 08	10.8	66.1	-.000 001	.000 744	.975	.003 88	10.8	69.5	-.000 001	.000 708	.975	.003 74	10.8	72.1	-.000 001	.000 682
874 500	550 000	.975	.004 42	11.8	66.7	-.000 001	.000 738	.975	.004 21	11.8	70.0	-.000 001	.000 702	.975	.004 05	11.8	72.7	-.000 001	.000 675
795 000	500 000	.975	.004 78	12.9	67.2	-.000 001	.000 730	.975	.004 55	12.9	70.6	-.000 001	.000 696	.975	.004 38	12.9	73.2	-.000 001	.000 670
715 500	450 000	.975	.005 28	14.4	68.0	-.000 001	.000 722	.975	.005 03	14.4	71.3	-.000 001	.000 688	.975	.004 86	14.4	74.0	-.000 001	.000 664
636 000	400 000	.975	.005 86	16.1	68.8	-.000 001	.000 715	.975	.005 58	16.1	72.2	-.000 001	.000 681	.975	.005 38	16.1	74.8	-.000 001	.000 657
556 500	350 000	.975	.006 57	18.2	69.1	-.000 002	.000 711	.975	.006 27	18.2	72.5	-.000 001	.000 679	.975	.006 04	18.2	75.1	-.000 001	.000 654
477 000	300 000	.975	.007 55	21.2	70.1	-.000 002	.000 700	.975	.007 21	21.2	73.5	-.000 002	.000 669	.975	.006 95	21.2	76.2	-.000 002	.000 645
397 500	250 000	.975	.008 90	25.4	71.5	-.000 002	.000 688	.975	.008 50	25.4	74.8	-.000 002	.000 658	.975	.008 21	25.4	77.5	-.000 002	.000 635
336 400	0 000	.975	.010 4	30.1	72.7	-.000 002	.000 679	.975	.009 90	30.1	76.0	-.000 002	.000 648	.975	.009 57	30.1	78.7	-.000 002	.000 626
266 800	000	.975	.012 7	37.9	74.8	-.000 003	.000 659	.975	.012 1	37.9	78.2	-.000 003	.000 631	.975	.011 7	37.9	80.8	-.000 002	.000 609
0 000	00	.972	.016 5	50.1	85.3	-.000 004	.000 645	.972	.015 8	50.1	88.6	-.000 003	.000 618	.972	.015 2	50.1	91.3	-.000 003	.000 597
000	0	.972	.020 1	62.5	86.5	-.000 004	.000 632	.972	.019 3	62.5	89.8	-.000 004	.000 606	.973	.018 7	62.5	92.5	-.000 004	.000 586
00	1	.972	.024 5	77.5	87.9	-.000 005	.000 620	.973	.023 5	77.5	91.2	-.000 005	.000 595	.973	.022 7	77.5	93.8	-.000 004	.000 576
0	2	.973	.029 9	96.4	89.4	-.000 006	.000 608	.973	.028 6	96.4	92.7	-.000 006	.000 583	.973	.027 8	96.4	95.3	-.000 005	.000 566

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.975	.002 66	7.67	72.1	-.000 001	.000 682	.975	.002 59	7.67	74.1	-.000 001	.000 664	.975	.002 54	7.67	75.7	-.000 001	.000 650
1 272 000	800 000	.975	.002 81	8.14	72.6	-.000 001	.000 679	.975	.002 73	8.14	74.4	-.000 001	.000 661	.975	.002 68	8.14	76.2	-.000 001	.000 647
1 192 500	750 000	.975	.002 97	8.67	72.9	-.000 001	.000 674	.975	.002 89	8.67	74.9	-.000 001	.000 657	.975	.002 83	8.67	76.5	-.000 001	.000 643
1 113 000	700 000	.975	.003 16	9.27	73.3	-.000 001	.000 671	.975	.003 08	9.27	75.3	-.000 001	.000 654	.975	.003 01	9.27	76.9	-.000 001	.000 639
1 033 500	650 000	.975	.003 37	9.98	73.8	-.000 001	.000 666	.975	.003 29	9.98	75.7	-.000 001	.000 649	.975	.003 22	9.98	77.4	-.000 001	.000 635
954 000	600 000	.975	.003 63	10.8	74.3	-.000 001	.000 661	.975	.003 54	10.8	76.3	-.000 001	.000 645	.975	.003 46	10.8	77.9	-.000 001	.000 631
874 500	550 000	.975	.003 93	11.8	74.9	-.000 001	.000 656	.975	.003 83	11.8	76.7	-.000 001	.000 639	.975	.003 75	11.8	78.5	-.000 001	.000 626
795 000	500 000	.975	.004 25	12.9	75.5	-.000 001	.000 650	.975	.004 15	12.9	77.4	-.000 001	.000 634	.975	.004 06	12.9	79.0	-.000 001	.000 621
715 500	450 000	.975	.004 71	14.4	76.2	-.000 001	.000 644	.975	.004 60	14.4	78.1	-.000 001	.000 628	.975	.004 50	14.4	79.8	-.000 001	.000 615
636 000	400 000	.975	.005 22	16.1	77.0	-.000 001	.000 637	.975	.005 10	16.1	78.9	-.000 001	.000 622	.975	.005 00	16.1	80.6	-.000 001	.000 610
556 500	350 000	.975	.005 87	18.2	77.3	-.000 001	.000 635	.975	.005 72	18.2	79.3	-.000 001	.000 620	.975	.005 60	18.2	80.9	-.000 001	.000 607
477 000	300 000	.975	.006 76	21.2	78.4	-.000 001	.000 627	.975	.006 60	21.2	80.2	-.000 001	.000 612	.975	.006 46	21.2	81.9	-.000 001	.000 599
397 500	250 000	.975	.007 98	25.4	79.7	-.000 002	.000 618	.975	.007 78	25.4	81.6	-.000 002	.000 602	.975	.007 63	25.4	83.2	-.000 002	.000 590
336 400	0 000	.975	.009 30	30.1	80.8	-.000 002	.000 609	.975	.009 09	30.1	82.8	-.000 002	.000 595	.975	.008 91	30.1	84.4	-.000 002	.000 583
266 800	000	.975	.011 4	37.9	83.1	-.000 002	.000 594	.975	.011 2	37.9	84.9	-.000 002	.000 579	.975	.010 9	37.9	86.6	-.000 002	.000 568
0 000	00	.972	.014 9	50.1	93.5	-.000 003	.000 582	.973	.014 5	50.1	95.3	-.000 003	.000 569	.973	.014 2	50.1	97.0	-.000 003	.000 558
000	0	.973	.018 2	62.5	94.7	-.000 004	.000 571	.973	.017 8	62.5	96.6	-.000 003	.000 559	.973	.017 5	62.5	98.3	-.000 003	.000 548
00	1	.973	.022 2	77.5	96.1	-.000 004	.000 561	.973	.021 7	77.5	97.9	-.000 004	.000 549	.973	.021 3	77.5	99.5	-.000 004	.000 540
0	2	.973	.027 1	96.4	97.5	-.000 005	.000 552	.973	.026 5	96.4	99.4	-.000 005	.000 540	.973	.026 0	96.4	101.	-.000 005	.000 530

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.975	.002 48	7.67	77.1	-.000 001	.000 637	.975	.002 44	7.67	78.5	-.000 001	.000 626	.975	.002 41	7.67	79.7	-.000 001	.000 618
1 272 000	800 000	.975	.002 62	8.14	77.6	-.000 001	.000 634	.975	.002 58	8.14	78.9	-.000 001	.000 624	.975	.002 54	8.14	80.1	-.000 001	.000 614
1 192 500	750 000	.975	.002 78	8.67	77.9	-.000 001	.000 631	.975	.002 73	8.67	79.3	-.000 001	.000 620	.975	.002 69	8.67	80.5	-.000 001	.000 611
1 113 000	700 000	.975	.002 96	9.27	78.3	-.000 001	.000 627	.975	.002 91	9.27	79.7	-.000 001	.000 616	.975	.002 86	9.27	80.9	-.000 001	.000 608
1 033 500	650 000	.975	.003 16	9.98	78.8	-.000 001	.000 623	.975	.003 10	9.98	80.1	-.000 001	.000 612	.975	.003 06	9.98	81.3	-.000 001	.000 603
954 000	600 000	.975	.003 39	10.8	79.3	-.000 001	.000 619	.975	.003 34	10.8	80.6	-.000 001	.000 609	.975	.003 29	10.8	81.9	-.000 001	.000 600
874 500	550 000	.975	.003 68	11.8	79.9	-.000 001	.000 614	.975	.003 62	11.8	81.2	-.000 001	.000 604	.975	.003 57	11.8	82.4	-.000 001	.000 596
795 000	500 000	.975	.003 99	12.9	80.5	-.000 001	.000 610	.975	.003 92	12.9	81.9	-.000 001	.000 599	.975	.003 86	12.9	83.1	-.000 001	.000 590
715 500	450 000	.975	.004 42	14.4	81.2	-.000 001	.000 604	.975	.004 35	14.4	82.5	-.000 001	.000 595	.975	.004 28	14.4	83.7	-.000 001	.000 586
636 000	400 000	.975	.004 91	16.1	82.0	-.000 001	.000 599	.975	.004 83	16.1	83.3	-.000 001	.000 589	.975	.004 76	16.1	84.5	-.000 001	.000 580
556 500	350 000	.975	.005 50	18.2	82.3	-.000 001	.000 596	.975	.005 42	18.2	83.6	-.000 001	.000 587	.975	.005 34	18.2	84.8	-.000 001	.000 578
477 000	300 000	.975	.006 35	21.2	83.4	-.000 001	.000 589	.975	.006 25	21.2	84.7	-.000 001	.000 579	.975	.006 16	21.2	85.9	-.000 001	.000 572
397 500	250 000	.975	.007 50	25.4	84.7	-.000 001	.000 580	.975	.007 39	25.4	86.0	-.000 001	.000 572	.975	.007 28	25.4	87.2	-.000 001	.000 563
336 400	0 000	.975	.008 76	30.1	85.8	-.000 002	.000 573	.975	.008 62	30.1	87.3	-.000 002	.000 564	.975	.008 51	30.1	88.4	-.000 002	.000 556
266 800	000	.975	.010 8	37.9	88.1	-.000 002	.000 559	.975	.010 6	37.9	89.4	-.000 002	.000 550	.975	.010 5	37.9	90.6	-.000 002	.000 543
0 000	00	.973	.014 0	50.1	98.5	-.000 003	.000 548	.973	.013 8	50.1	99.8	-.000 003	.000 541	.973	.013 6	50.1	101.	-.000 002	.000 533
000	0	.973	.017 2	62.5	99.7	-.000 003	.000 540	.973	.016 9	62.5	101.	-.000 003	.000 532	.973	.016 7	62.5	102.	-.000 003	.000 524
00	1	.973	.021 0	77.5	101.	-.000 004	.000 531	.973	.020 7	77.5	102.	-.000 004	.000 523	.973	.020 4	77.5	104.	-.000 004	.000 517
0	2	.973	.025 6	96.4	102.	-.000 005	.000 521	.973	.025 3	96.4	104.	-.000 004	.000 515	.973	.025 0	96.4	105.	-.000 004	.000 508

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

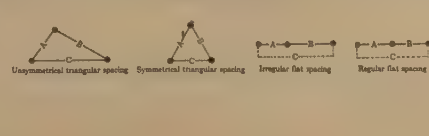


TABLE LIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

120 MILES—193.12 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.969	.004 32	11.0	78.7	-.000 001	.000 771	.969	.004 12	11.0	82.3	-.000 001	.000 735	.969	.003 97	11.0	85.2	-.000 001	.000 709
600 000	.969	.004 61	11.8	79.4	-.000 001	.000 764	.969	.004 41	11.8	82.9	-.000 001	.000 729	.969	.004 25	11.8	85.9	-.000 001	.000 703
550 000	.969	.004 97	12.8	80.0	-.000 001	.000 758	.969	.004 74	12.8	83.7	-.000 001	.000 723	.969	.004 58	12.8	86.5	-.000 001	.000 699
500 000	.969	.005 39	14.1	80.7	-.000 001	.000 751	.969	.005 15	14.1	84.3	-.000 001	.000 718	.969	.004 97	14.1	87.2	-.000 001	.000 693
450 000	.969	.005 91	15.6	81.4	-.000 001	.000 744	.969	.005 64	15.6	85.1	-.000 001	.000 710	.969	.005 45	15.6	87.9	-.000 001	.000 687
400 000	.969	.006 55	17.4	82.5	-.000 002	.000 735	.969	.006 26	17.4	86.2	-.000 001	.000 703	.969	.006 05	17.4	89.0	-.000 001	.000 680
350 000	.969	.007 37	19.9	83.4	-.000 002	.000 727	.969	.007 04	19.9	87.1	-.000 002	.000 695	.969	.006 80	19.9	90.0	-.000 002	.000 671
300 000	.969	.008 44	23.1	84.7	-.000 002	.000 716	.969	.008 08	23.1	88.2	-.000 002	.000 685	.969	.007 82	23.1	91.2	-.000 002	.000 663
250 000	.969	.009 95	27.7	86.0	-.000 002	.000 704	.969	.009 53	27.7	89.5	-.000 002	.000 675	.969	.009 23	27.7	92.5	-.000 002	.000 653
0000	.969	.011 5	32.6	88.0	-.000 003	.000 694	.969	.011 1	32.6	91.6	-.000 002	.000 664	.969	.010 7	32.6	94.6	-.000 002	.000 643
000	.969	.014 2	41.1	89.8	-.000 003	.000 680	.969	.013 7	41.1	93.3	-.000 003	.000 652	.969	.013 2	41.1	96.3	-.000 003	.000 631
00	.969	.017 6	51.7	91.5	-.000 004	.000 666	.969	.016 9	51.7	95.1	-.000 004	.000 640	.969	.016 4	51.7	98.1	-.000 003	.000 620
0	.969	.021 8	65.2	93.4	-.000 005	.000 655	.969	.020 9	65.2	96.9	-.000 004	.000 628	.969	.020 3	65.2	99.9	-.000 004	.000 609
1	.969	.026 9	82.2	95.3	-.000 006	.000 642	.969	.025 5	82.2	98.9	-.000 005	.000 617	.969	.025 1	82.2	102.	-.000 005	.000 599
2	.969	.033 3	104.	97.4	-.000 007	.000 630	.969	.032 0	104.	101.	-.000 007	.000 606	.969	.031 1	104.	104.	-.000 006	.000 588

	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.969	.003 85	11.0	87.6	-.000 001	.000 688	.969	.003 77	11.0	89.7	-.000 001	.000 672	.969	.003 69	11.0	91.5	-.000 001	.000 658
600 000	.969	.004 13	11.8	88.3	-.000 001	.000 683	.969	.004 03	11.8	90.3	-.000 001	.000 668	.969	.003 95	11.8	92.1	-.000 001	.000 653
550 000	.969	.004 45	12.8	88.9	-.000 001	.000 678	.969	.004 35	12.8	91.0	-.000 001	.000 663	.969	.004 25	12.8	92.8	-.000 001	.000 649
500 000	.969	.004 84	14.1	89.6	-.000 001	.000 674	.969	.004 72	14.1	91.6	-.000 001	.000 657	.969	.004 62	14.1	93.4	-.000 001	.000 644
450 000	.969	.005 30	15.6	90.3	-.000 001	.000 668	.969	.005 18	15.6	92.5	-.000 001	.000 652	.969	.005 08	15.6	94.2	-.000 001	.000 639
400 000	.969	.005 88	17.4	91.4	-.000 001	.000 661	.969	.005 74	17.4	93.5	-.000 001	.000 645	.969	.005 63	17.4	95.3	-.000 001	.000 632
350 000	.969	.006 62	19.9	92.5	-.000 001	.000 653	.969	.006 47	19.9	94.5	-.000 001	.000 638	.969	.006 35	19.9	96.3	-.000 001	.000 626
300 000	.969	.007 61	23.1	93.6	-.000 002	.000 645	.969	.007 44	23.1	95.6	-.000 002	.000 631	.969	.007 28	23.1	97.4	-.000 002	.000 618
250 000	.969	.008 97	27.7	94.9	-.000 002	.000 636	.969	.008 77	27.7	96.9	-.000 002	.000 621	.969	.008 61	27.7	98.8	-.000 002	.000 609
0000	.969	.010 4	32.6	96.9	-.000 002	.000 626	.969	.010 2	32.6	99.0	-.000 002	.000 613	.969	.010 0	32.6	101.	-.000 002	.000 601
000	.969	.012 9	41.1	98.7	-.000 003	.000 615	.969	.012 6	41.1	101.	-.000 003	.000 602	.969	.012 4	41.1	102.	-.000 002	.000 590
00	.969	.016 0	51.7	100.	-.000 003	.000 605	.969	.015 6	51.7	102.	-.000 003	.000 592	.969	.015 3	51.7	104.	-.000 003	.000 581
0	.969	.019 8	65.2	102.	-.000 004	.000 594	.969	.019 4	65.2	104.	-.000 004	.000 582	.969	.019 0	65.2	106.	-.000 004	.000 571
1	.969	.024 5	82.2	104.	-.000 005	.000 584	.969	.024 0	82.2	106.	-.000 005	.000 571	.969	.023 6	82.2	108.	-.000 004	.000 562
2	.969	.030 4	104.	106.	-.000 006	.000 574	.969	.029 8	104.	108.	-.000 006	.000 563	.969	.029 2	104.	110.	-.000 005	.000 552

	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.969	.003 62	11.0	93.0	-.000 001	.000 646	.970	.003 56	11.0	94.5	-.000 001	.000 636	.970	.003 51	11.0	95.8	-.000 001	.000 627
600 000	.969	.003 87	11.8	93.7	-.000 001	.000 642	.970	.003 82	11.8	95.2	-.000 001	.000 632	.970	.003 76	11.8	96.5	-.000 001	.000 623
550 000	.969	.004 18	12.8	94.3	-.000 001	.000 638	.970	.004 11	12.8	95.8	-.000 001	.000 627	.970	.004 06	12.8	97.1	-.000 001	.000 619
500 000	.969	.004 55	14.1	95.1	-.000 001	.000 633	.970	.004 47	14.1	96.5	-.000 001	.000 623	.970	.004 41	14.1	97.8	-.000 001	.000 614
450 000	.969	.004 98	15.6	95.8	-.000 001	.000 627	.970	.004 91	15.6	97.3	-.000 001	.000 618	.970	.004 84	15.6	98.6	-.000 001	.000 609
400 000	.969	.005 53	17.4	97.0	-.000 001	.000 621	.970	.005 45	17.4	98.4	-.000 001	.000 612	.970	.005 37	17.4	99.7	-.000 001	.000 604
350 000	.969	.006 24	19.9	97.9	-.000 001	.000 615	.970	.006 14	19.9	99.4	-.000 001	.000 606	.970	.006 06	19.9	101.	-.000 001	.000 598
300 000	.969	.007 17	23.1	99.0	-.000 001	.000 608	.970	.007 06	23.1	100.	-.000 001	.000 599	.970	.006 96	23.1	102.	-.000 001	.000 590
250 000	.969	.008 47	27.7	100.	-.000 002	.000 600	.970	.008 34	27.7	102.	-.000 002	.000 590	.970	.008 24	27.7	103.	-.000 002	.000 583
0000	.969	.009 85	32.6	102.	-.000 002	.000 592	.969	.009 69	32.6	104.	-.000 002	.000 582	.969	.009 58	32.6	105.	-.000 002	.000 575
000	.969	.012 2	41.1	104.	-.000 002	.000 581	.969	.012 0	41.1	106.	-.000 002	.000 573	.969	.011 9	41.1	107.	-.000 002	.000 565
00	.969	.015 1	51.7	106.	-.000 003	.000 571	.969	.014 9	51.7	107.	-.000 003	.000 563	.969	.014 7	51.7	109.	-.000 003	.000 556
0	.969	.018 7	65.2	108.	-.000 004	.000 562	.969	.018 5	65.2	109.	-.000 003	.000 555	.969	.018 2	65.2	110.	-.000 003	.000 548
1	.969	.023 2	82.2	110.	-.000 004	.000 554	.969	.022 9	82.2	111.	-.000 004	.000 545	.969	.022 6	82.2	112.	-.000 004	.000 539
2	.969	.028 8	104.	112.	-.000 005	.000 544	.969	.028 4	104.	113.	-.000 005	.000 537	.969	.028 1	104.	114.	-.000 005	.000 531

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

120 MILES—193.12 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.970	.003 57	8.34	69.6	−.000 001	.000 840	.970	.003 39	8.34	73.2	−.000001	.000797	.970	.003 26	8.34	76.2	−.000001	.000766
1 272 000	800 000	.970	.003 76	8.84	70.1	−.000001	.000 834	.970	.003 58	8.84	73.7	−.000001	.000 792	.970	.003 44	8.84	76.5	−.000001	.000763
1 192 500	750 000	.970	.003 99	9.42	70.5	−.000001	.000 829	.970	.003 79	9.42	74.1	−.000001	.000788	.970	.003 64	9.42	77.0	−.000001	.000758
1 113 000	700 000	.970	.004 23	10.1	70.9	−.000 001	.000 823	.970	.004 03	10.1	74.5	−.000001	.000783	.970	.003 87	10.1	77.5	−.000001	.000753
1 033 500	650 000	.970	.004 52	10.8	71.4	−.000 001	.000 816	.970	.004 30	10.8	75.1	−.000001	.000777	.970	.004 13	10.8	78.0	−.000001	.000747
954 000	600 000	.970	.004 85	11.7	72.0	−.000001	.000 810	.970	.004 61	11.7	75.7	−.000001	.000771	.970	.004 44	11.7	78.6	−.000001	.000743
874 500	550 000	.970	.005 25	12.8	72.6	−.000 001	.000 803	.970	.005 00	12.8	76.2	−.000001	.000764	.970	.004 81	12.8	79.1	−.000001	.000735
795 000	500 000	.970	.005 68	14.0	73.2	−.000 002	.000 795	.970	.005 41	14.0	76.9	−.000001	.000758	.970	.005 21	14.0	79.7	−.000001	.000729
715 500	450 000	.970	.006 28	15.6	74.0	−.000 002	.000 787	.970	.005 98	15.6	77.6	−.000002	.000750	.970	.005 77	15.6	80.6	−.000001	.000724
636 000	400 000	.970	.006 96	17.5	74.9	−.000 002	.000 778	.970	.006 63	17.5	78.6	−.000002	.000741	.970	.006 39	17.5	81.4	−.000002	.000715
556 500	350 000	.970	.007 81	19.8	75.3	−.000 002	.000 775	.970	.007 45	19.8	78.9	−.000 002	.000739	.970	.007 17	19.8	81.8	−.000002	.000712
477 000	300 000	.970	.008 97	23.1	76.3	−.000 002	.000 763	.970	.008 56	23.1	80.0	−.000 002	.000728	.970	.008 25	23.1	83.0	−.000 002	.000702
397 500	250 000	.970	.010 6	27.6	77.9	−.000 003	.000 750	.970	.010 1	27.6	81.5	−.000 002	.000 716	.970	.009 75	27.6	84.4	−.000 002	.000 691
336 400	0 000	.970	.012 3	32.7	79.1	−.000 003	.000 739	.970	.011 8	32.7	82.8	−.000 003	.000 706	.970	.011 4	32.7	85.7	−.000 003	.000 682
266 800	000	.970	.015 1	41.2	81.5	−.000 004	.000 718	.970	.014 4	41.2	85.1	−.000 003	.000 687	.970	.013 9	41.2	88.0	−.000 003	.000 663
0 000	00	.967	.019 6	54.5	93.0	−.000 005	.000 703	.967	.018 7	54.5	96.5	−.000 004	.000 673	.967	.018 1	54.5	99.5	−.000 004	.000 651
000	0	.967	.023 9	68.0	94.3	−.000 006	.000 689	.967	.022 9	68.0	97.9	−.000 005	.000 660	.967	.022 2	68.0	101.	−.000 005	.000 639
00	1	.967	.029 1	84.3	95.8	−.000 007	.000 675	.967	.027 9	84.3	99.4	−.000 006	.000 648	.968	.027 0	84.3	102.	−.000 006	.000 627
0	2	.967	.035 5	105.	97.5	−.000 008	.000 662	.968	.034 0	105.	101.	−.000 007	.000 635	.968	.033 0	105.	104.	−.000 007	.000 616

CIRCULAR MILS OR A. W. G (B & S)	COPPER EQUIVALENT	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.970	.003 16	8.34	78.5	−.000001	.000 743	.970	.003 08	8.34	80.7	−.000001	.000724	.970	.003 01	8.34	82.5	−.000 001	.000 708
1 272 000	800 000	.970	.003 33	8.84	79.0	−.000 001	.000 739	.970	.003 25	8.84	81.0	−.000 001	.000720	.970	.003 18	8.84	82.9	−.000001	.000 705
1 192 500	750 000	.970	.003 53	9.42	79.4	−.000001	.000 734	.970	.003 44	9.42	81.5	−.000001	.000 715	.970	.003 36	9.42	83.3	−.000 001	.000 700
1 113 000	700 000	.970	.003 76	10.1	79.8	−.000 001	.000 731	.970	.003 66	10.1	82.0	−.000 001	.000 712	.970	.003 58	10.1	83.8	−.000 001	.000 696
1 033 500	650 000	.970	.004 01	10.8	80.3	−.000001	.000 725	.970	.003 91	10.8	82.5	−.000 001	.000 707	.970	.003 83	10.8	84.2	−.000 001	.000 691
954 000	600 000	.970	.004 31	11.7	80.9	−.000001	.000720	.970	.004 20	11.7	83.1	−.000 001	.000 702	.970	.004 11	11.7	84.8	−.000 001	.000 687
874 500	550 000	.970	.004 67	12.8	81.5	−.000001	.000 714	.970	.004 55	12.8	83.5	−.000001	.000 696	.970	.004 46	12.8	85.4	−.000 001	.000 682
795 000	500 000	.970	.005 06	14.0	82.2	−.000001	.000 708	.970	.004 93	14.0	84.3	−.000 001	.000 690	.970	.004 83	14.0	86.0	−.000 001	.000 676
715 500	450 000	.970	.005 59	15.6	83.0	−.000001	.000 701	.970	.005 46	15.6	85.1	−.000001	.000 684	.970	.005 35	15.6	86.9	−.000 001	.000 670
636 000	400 000	.970	.006 20	17.5	83.8	−.000 001	.000 694	.970	.006 05	17.5	85.9	−.000 001	.000 677	.970	.005 94	17.5	87.7	−.000 001	.000 664
556 500	350 000	.970	.006 97	19.8	84.2	−.000 002	.000 691	.970	.006 80	19.8	86.3	−.000 002	.000 675	.970	.006 66	19.8	88.1	−.000 001	.000 661
477 000	300 000	.970	.008 03	23.1	85.4	−.000 002	.000 683	.970	.007 84	23.1	87.4	−.000 002	.000 667	.970	.007 67	23.1	89.2	−.000 002	.000 652
397 500	250 000	.970	.009 48	27.6	86.8	−.000 002	.000 672	.970	.009 25	27.6	88.8	−.000 002	.000 656	.970	.009 06	27.6	90.6	−.000 002	.000 643
336 400	0 000	.970	.011 1	32.7	88.0	−.000 002	.000 663	.970	.010 8	32.7	90.2	−.000 002	.000 648	.970	.010 6	32.7	92.0	−.000 002	.000 634
266 800	000	.970	.013 6	41.2	90.5	−.000 003	.000 646	.970	.013 3	41.2	92.5	−.000 003	.000 631	.970	.013 0	41.2	94.3	−.000 003	.000 619
0 000	00	.967	.017 7	54.5	102.	−.000 004	.000 634	.967	.017 3	54.5	104.	−.000 004	.000 620	.967	.016 9	54.5	106.	−.000 003	.000 608
000	0	.967	.021 6	68.0	103.	−.000 005	.000 622	.967	.021 2	68.0	105.	−.000 004	.000 609	.968	.020 7	68.0	107.	−.000 004	.000 597
00	1	.968	.026 3	84.3	105.	−.000 005	.000 611	.968	.025 8	84.3	107.	−.000 005	.000 598	.968	.025 3	84.3	109.	−.000 005	.000 588
0	2	.968	.032 2	105.	106.	−.000 007	.000 601	.968	.031 5	105.	108.	−.000 006	.000 588	.968	.030 9	105.	110.	−.000 006	.000 577

CIRCULAR MILS OR A. W. G (B & S)	COPPER EQUIVALENT	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.970	.002 95	8.34	84.0	−.000 001	.000 694	.970	.002 90	8.34	85.4	−.000 001	.000 682	.970	.002 86	8.34	86.7	−.000 001	.000 672
1 272 000	800 000	.970	.003 11	8.84	84.5	−.000 001	.000 690	.970	.003 07	8.84	85.9	−.000 001	.000 680	.970	.003 02	8.84	87.2	−.000 001	.000 669
1 192 500	750 000	.970	.003 30	9.42	84.8	−.000001	.000 687	.970	.003 24	9.42	86.4	−.000 001	.000 675	.970	.003 20	9.42	87.7	−.000 001	.000 665
1 113 000	700 000	.970	.003 51	10.1	85.3	−.000001	.000 683	.970	.003 45	10.1	86.7	−.000001	.000 671	.970	.003 40	10.1	88.0	−.000 001	.000 662
1 033 500	650 000	.970	.003 75	10.8	85.8	−.000 001	.000 678	.970	.003 69	10.8	87.2	−.000 001	.000 667	.970	.003 64	10.8	88.5	−.000 001	.000 657
954 000	600 000	.970	.004 03	11.7	86.4	−.000 001	.000 674	.970	.003 97	11.7	87.8	−.000001	.000 663	.970	.003 91	11.7	89.2	−.000 001	.000 653
874 500	550 000	.970	.004 37	12.8	87.0	−.000001	.000 669	.970	.004 31	12.8	88.4	−.000 001	.000 658	.970	.004 24	12.8	89.7	−.000 001	.000 649
795 000	500 000	.970	.004 74	14.0	87.7	−.000 001	.000 664	.970	.004 66	14.0	89.1	−.000001	.000 652	.970	.004 59	14.0	90.4	−.000 001	.000 643
715 500	450 000	.970	.005 25	15.6	88.4	−.000 001	.000 658	.970	.005 17	15.6	89.8	−.000001	.000 648	.970	.005 09	15.6	91.2	−.000 001	.000 638
636 000	400 000	.970	.005 83	17.5	89.3	−.000 001	.000 652	.970	.005 74	17.5	90.7	−.000001	.000 642	.970	.005 65	17.5	92.0	−.000 001	.000 632
556 500	350 000	.970	.006 54	19.8	89.6	−.000 001	.000 649	.970	.006 44	19.8	91.0	−.000001	.000 639	.970	.006 35	19.8	92.4	−.000 001	.000 630
477 000	300 000	.970	.007 54	23.1	90.8	−.000 002	.000 642	.970	.007 42	23.1	92.3	−.000 002	.000 631	.970	.007 32	23.1	93.6	−.000 002	.000 623
397 500	250 000	.970	.008 91	27.6	92.3	−.000 002	.000 632	.970	.008 78	27.6	93.7	−.000 002	.000 623	.970	.008 65	27.6	95.0	−.000 002	.000 613
336 400	0 000	.970	.010 4	32.7	93.5	−.000 002	.000 624	.970	.010 2	32.7	95.0	−.000 002	.000 614	.970	.010 1	32.7	96.2	−.000 002	.000 606
266 800	000	.970	.012 8	41.2	95.9	−.000 003	.000 608	.970	.012 6	41.2	97.4	−.000 003	.000 599	.970	.012 4	41.2	98.7	−.000 002	.000 592
0 000	00	.968	.016 6	54.5	107.	−.000 003	.000 597	.968	.016 4	54.5	109.	−.000 003	.000 589	.968	.016 2	54.5	110.	−.000 003	.000 580
000	0	.968	.020 4	68.0	109.	−.000 004	.000 588	.968	.020 1	68.0	110.	−.000 004	.000 579	.968	.019 8	68.0	111.	−.000 004	.000 571
00	1	.968	.024 9	84.3	110.	−.000 005	.000 578	.968	.024 6	84.3	112.	−.000 005	.000 570	.968	.024 2	84.3	113.	−.000 005	.000 563
0	2	.968	.030 4	105.	112.	−.000 006	.000 567	.968	.030 0	105.	113.	−.000 006	.000 560	.968	.029 6	105.	115.	−.000 006	.000 553

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

In which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

130 MILES—209.22 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

7 FEET—2.134 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.005 07	11.9	85.0	−.000 001	.000 833
600 000	.964	.005 41	12.8	85.8	−.000 002	.000 826
550 000	.964	.005 82	13.9	86.4	−.000 002	.000 819
500 000	.964	.006 32	15.2	87.2	−.000 002	.000 811
450 000	.964	.006 92	16.8	88.0	−.000 002	.000 804
400 000	.964	.007 67	18.8	89.2	−.000 002	.000 795
350 000	.964	.008 64	21.4	90.2	−.000 002	.000 786
300 000	.964	.009 90	24.9	91.5	−.000 003	.000 774
250 000	.964	.011 7	29.9	93.0	−.000 003	.000 761
0000	.964	.013 5	35.2	95.2	−.000 003	.000 750
000	.964	.016 7	44.4	97.1	−.000 004	.000 734
00	.964	.020 6	55.9	99.0	−.000 005	.000 720
0	.964	.025 5	70.4	101.	−.000 006	.000 707
1	.964	.031 5	88.8	103.	−.000 007	.000 693
2	.964	.039 0	112.	105.	−.000 009	.000 681

9 FEET—2.743 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 83	11.9	89.0	−.000 001	.000 795
600 000	.964	.005 16	12.8	89.6	−.000 001	.000 788
550 000	.964	.005 56	13.9	90.4	−.000 001	.000 782
500 000	.964	.006 04	15.2	91.1	−.000 002	.000 776
450 000	.964	.006 61	16.8	92.0	−.000 002	.000 768
400 000	.964	.007 34	18.8	93.1	−.000 002	.000 760
350 000	.964	.008 26	21.4	94.2	−.000 002	.000 751
300 000	.964	.009 47	24.9	95.4	−.000 002	.000 741
250 000	.964	.011 2	29.9	96.8	−.000 003	.000 729
0000	.964	.013 0	35.2	99.0	−.000 003	.000 718
000	.964	.016 0	44.4	101.	−.000 004	.000 705
00	.964	.019 8	55.9	103.	−.000 005	.000 692
0	.964	.024 5	70.4	105.	−.000 006	.000 679
1	.964	.030 3	88.8	107.	−.000 007	.000 666
2	.964	.037 6	112.	109.	−.000 008	.000 655

11 FEET—3.353 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 66	11.9	92.1	−.000 001	.000 767
600 000	.964	.004 98	12.8	92.9	−.000 001	.000 760
550 000	.964	.005 37	13.9	93.5	−.000 001	.000 755
500 000	.964	.005 83	15.2	94.3	−.000 001	.000 749
450 000	.964	.006 39	16.8	95.1	−.000 002	.000 742
400 000	.964	.007 09	18.8	96.2	−.000 002	.000 734
350 000	.964	.007 98	21.4	97.3	−.000 002	.000 725
300 000	.964	.009 16	24.9	98.6	−.000 002	.000 716
250 000	.964	.010 8	29.9	100.	−.000 003	.000 706
0000	.964	.012 5	35.2	102.	−.000 003	.000 695
000	.964	.015 5	44.4	104.	−.000 004	.000 682
00	.964	.019 2	55.9	106.	−.000 004	.000 670
0	.964	.023 8	70.4	108.	−.000 005	.000 659
1	.964	.029 4	88.8	110.	−.000 006	.000 647
2	.964	.036 5	112.	112.	−.000 008	.000 636

13 FEET—3.962 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 52	11.9	94.6	−.000 001	.000 743
600 000	.964	.004 84	12.8	95.4	−.000 001	.000 738
550 000	.964	.005 21	13.9	96.1	−.000 001	.000 733
500 000	.964	.005 67	15.2	96.8	−.000 001	.000 728
450 000	.964	.006 22	16.8	97.6	−.000 002	.000 722
400 000	.964	.006 89	18.8	98.8	−.000 002	.000 714
350 000	.964	.007 76	21.4	100.	−.000 002	.000 706
300 000	.964	.008 92	24.9	101.	−.000 002	.000 697
250 000	.964	.010 5	29.9	103.	−.000 002	.000 687
0000	.964	.012 2	35.2	105.	−.000 003	.000 677
000	.964	.015 1	44.4	107.	−.000 003	.000 665
00	.964	.018 7	55.9	109.	−.000 004	.000 654
0	.964	.023 2	70.4	111.	−.000 005	.000 642
1	.964	.028 8	88.8	113.	−.000 006	.000 632
2	.964	.035 6	112.	115.	−.000 007	.000 620

15 FEET—4.572 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 42	11.9	97.0	−.000 001	.000 727
600 000	.964	.004 73	12.8	97.6	−.000 001	.000 722
550 000	.964	.005 09	13.9	98.4	−.000 001	.000 716
500 000	.964	.005 53	15.2	99.0	−.000 001	.000 710
450 000	.964	.006 07	16.8	99.9	−.000 001	.000 705
400 000	.964	.006 73	18.8	101.	−.000 002	.000 697
350 000	.964	.007 58	21.4	102.	−.000 002	.000 690
300 000	.964	.008 72	24.9	103.	−.000 002	.000 682
250 000	.964	.010 3	29.9	105.	−.000 002	.000 672
0000	.964	.012 0	35.2	107.	−.000 003	.000 663
000	.964	.014 8	44.4	109.	−.000 003	.000 651
00	.964	.018 3	55.9	111.	−.000 004	.000 639
0	.964	.022 7	70.4	113.	−.000 005	.000 629
1	.964	.028 1	88.8	115.	−.000 006	.000 618
2	.964	.034 9	112.	117.	−.000 007	.000 609

17 FEET—5.182 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 32	11.9	98.9	−.000 001	.000 711
600 000	.964	.004 63	12.8	99.5	−.000 001	.000 706
550 000	.964	.004 99	13.9	100.	−.000 001	.000 701
500 000	.964	.005 42	15.2	101.	−.000 001	.000 696
450 000	.964	.005 95	16.8	102.	−.000 001	.000 691
400 000	.964	.006 59	18.8	103.	−.000 002	.000 683
350 000	.964	.007 44	21.4	104.	−.000 002	.000 677
300 000	.964	.008 54	24.9	105.	−.000 002	.000 668
250 000	.964	.010 1	29.9	107.	−.000 002	.000 659
0000	.964	.011 7	35.2	109.	−.000 003	.000 650
000	.964	.014 5	44.4	111.	−.000 003	.000 638
00	.964	.018 0	55.9	113.	−.000 004	.000 628
0	.964	.022 3	70.4	115.	−.000 005	.000 618
1	.964	.027 6	88.8	117.	−.000 006	.000 607
2	.964	.034 3	112.	119.	−.000 007	.000 597

19 FEET—5.791 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 25	11.9	101	−.000 001	.000 698
600 000	.964	.004 54	12.8	101	−.000 001	.000 693
550 000	.964	.004 90	13.9	102	−.000 001	.000 690
500 000	.964	.005 33	15.2	103	−.000 001	.000 684
450 000	.964	.005 84	16.8	103	−.000 001	.000 678
400 000	.964	.006 48	18.8	105	−.000 001	.000 672
350 000	.964	.007 31	21.4	106	−.000 002	.000 665
300 000	.964	.008 41	24.9	107	−.000 002	.000 657
250 000	.964	.009 93	29.9	108	−.000 002	.000 648
0000	.964	.011 5	35.2	111	−.000 003	.000 639
000	.964	.014 3	44.4	113	−.000 003	.000 628
00	.964	.017 7	55.9	114	−.000 004	.000 618
0	.964	.021 9	70.4	116	−.000 005	.000 607
1	.964	.027 2	88.8	119	−.000 006	.000 598
2	.964	.033 7	112.	121	−.000 007	.000 588

21 FEET—6.401 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 18	11.9	102	−.000 001	.000 687
600 000	.964	.004 47	12.8	103	−.000 001	.000 683
550 000	.964	.004 82	13.9	103	−.000 001	.000 678
500 000	.964	.005 24	15.2	104	−.000 001	.000 673
450 000	.964	.005 75	16.8	105	−.000 001	.000 668
400 000	.964	.006 38	18.8	106	−.000 001	.000 661
350 000	.964	.007 20	21.4	107	−.000 002	.000 655
300 000	.964	.008 28	24.9	109	−.000 002	.000 647
250 000	.964	.009 77	29.9	110	−.000 002	.000 638
0000	.964	.011 4	35.2	112	−.000 002	.000 629
000	.964	.014 1	44.4	114	−.000 003	.000 619
00	.964	.017 4	55.9	116	−.000 004	.000 609
0	.964	.021 6	70.4	118	−.000 004	.000 600
1	.964	.026 8	88.8	120	−.000 005	.000 589
2	.964	.033 3	112.	122	−.000 007	.000 580

23 FEET—7.010 METERS

Circular Mils or A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.964	.004 12	11.9	103	−.000 001	.000 678
600 000	.964	.004 41	12.8	104	−.000 001	.000 673
550 000	.964	.004 76	13.9	105	−.000 001	.000 669
500 000	.964	.005 17	15.2	106	−.000 001	.000 664
450 000	.964	.005 67	16.8	107	−.000 001	.000 659
400 000	.964	.006 30	18.8	108	−.000 001	.000 652
350 000	.964	.007 10	21.4	109	−.000 002	.000 646
300 000	.964	.008 16	24.9	110	−.000 002	.000 638
250 000	.964	.009 66	29.9	111	−.000 002	.000 630
0000	.964	.011 2	35.2	114	−.000 002	.000 621
000	.964	.013 9	44.4	116	−.000 003	.000 611
00	.964	.017 2	55.9	117	−.000 004	.000 601
0	.964	.021 4	70.4	119	−.000 004	.000 592
1	.964	.026 5	88.8	122	−.000 005	.000 583
2	.964	.032 9	112.	124	−.000 006	.000 574

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE LXII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

130 MILES—209.22 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

7 FEET—2.134 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin 61%	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00419	9.00	75.3	−.000001	.000909
1 272 000	800 000	.965	.00441	9.55	75.8	−.000001	.000902
1 192 500	750 000	.965	.00467	10.2	76.2	−.000001	.000897
1 113 000	700 000	.965	.00496	10.9	76.7	−.000001	.000891
1 033 500	650 000	.965	.00529	11.7	77.3	−.000002	.000883
954 000	600 000	.965	.00568	12.7	77.9	−.000002	.000876
874 500	550 000	.965	.00615	13.8	78.5	−.000002	.000869
795 000	500 000	.965	.00665	15.1	79.2	−.000002	.000860
715 500	450 000	.965	.00735	16.9	80.1	−.000002	.000851
636 000	400 000	.965	.00815	18.9	81.0	−.000002	.000842
556 500	350 000	.965	.00914	21.3	81.4	−.000003	.000838
477 000	300 000	.965	.0105	24.9	82.6	−.000003	.000825
397 500	250 000	.965	.0124	29.9	84.3	−.000003	.000811
336 400	0 000	.965	.0144	35.3	85.6	−.000004	.000799
266 800	000	.965	.0177	44.5	88.2	−.000005	.000776
0 000	00	.961	.0229	58.7	101.	−.000006	.000760
000	0	.961	.0280	73.3	102.	−.000007	.000744
00	1	.962	.0341	90.9	104.	−.000008	.000730
0	2	.962	.0416	113.	106.	−.000010	.000717

9 FEET—2.743 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00397	9.00	79.2	−.000001	.000862
1 272 000	800 000	.965	.00419	9.55	79.7	−.000001	.000857
1 192 500	750 000	.965	.00444	10.2	80.2	−.000001	.000852
1 113 000	700 000	.965	.00472	10.9	80.6	−.000001	.000847
1 033 500	650 000	.965	.00504	11.7	81.2	−.000001	.000840
954 000	600 000	.965	.00540	12.7	81.9	−.000002	.000834
874 500	550 000	.965	.00585	13.8	82.4	−.000002	.000826
795 000	500 000	.965	.00634	15.1	83.2	−.000002	.000820
715 500	450 000	.965	.00701	16.9	84.0	−.000002	.000811
636 000	400 000	.965	.00777	18.9	85.0	−.000002	.000802
556 500	350 000	.965	.00873	21.3	85.4	−.000002	.000799
477 000	300 000	.965	.0100	24.9	86.6	−.000003	.000788
397 500	250 000	.965	.0118	29.9	88.1	−.000003	.000775
336 400	0 000	.965	.0138	35.3	89.6	−.000004	.000763
266 800	000	.965	.0169	44.5	92.1	−.000004	.000743
0 000	00	.961	.0220	58.7	104.	−.000005	.000728
000	0	.962	.0269	73.3	106.	−.000007	.000713
00	1	.962	.0327	91.0	108.	−.000008	.000701
0	2	.962	.0399	113.	110.	−.000009	.000687

11 FEET—3.353 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00382	9.00	82.4	−.000001	.000829
1 272 000	800 000	.965	.00403	9.55	82.8	−.000001	.000825
1 192 500	750 000	.965	.00427	10.2	83.3	−.000001	.000820
1 113 000	700 000	.965	.00454	10.9	83.8	−.000001	.000815
1 033 500	650 000	.965	.00484	11.7	84.3	−.000001	.000808
954 000	600 000	.965	.00520	12.7	85.0	−.000001	.000803
874 500	550 000	.965	.00563	13.8	85.6	−.000002	.000795
795 000	500 000	.965	.00610	15.1	86.3	−.000002	.000739
715 500	450 000	.965	.00676	16.9	87.2	−.000002	.000783
636 000	400 000	.965	.00749	18.9	88.1	−.000002	.000774
556 500	350 000	.965	.00840	21.3	88.5	−.000002	.000770
477 000	300 000	.965	.00967	24.9	89.8	−.000002	.000759
397 500	250 000	.965	.0114	29.9	91.4	−.000003	.000748
336 400	0 000	.965	.0133	35.3	92.7	−.000003	.000738
266 800	000	.965	.0163	44.5	95.2	−.000004	.000717
0 000	00	.961	.0212	58.7	108.	−.000005	.000703
000	0	.962	.0260	73.4	109.	−.000006	.000691
00	1	.962	.0316	91.0	111.	−.000007	.000678
0	2	.962	.0387	113.	113.	−.000009	.000666

13 FEET—3.962 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00370	9.00	85.0	−.000001	.000803
1 272 000	800 000	.965	.00391	9.55	85.5	−.000001	.000799
1 192 500	750 000	.965	.00413	10.2	85.9	−.000001	.000794
1 113 000	700 000	.965	.00440	10.9	86.4	−.000001	.000790
1 033 500	650 000	.965	.00470	11.7	86.9	−.000001	.000784
954 000	600 000	.965	.00505	12.7	87.5	−.000001	.000779
874 500	550 000	.965	.00547	13.8	88.2	−.000001	.000772
795 000	500 000	.965	.00592	15.1	89.0	−.000002	.000766
715 500	450 000	.965	.00655	16.9	89.7	−.000002	.000758
636 000	400 000	.965	.00727	18.9	90.6	−.000002	.000750
556 500	350 000	.965	.00817	21.3	91.0	−.000002	.000748
477 000	300 000	.965	.00941	24.9	92.3	−.000002	.000739
397 500	250 000	.965	.0111	29.9	93.9	−.000003	.000727
336 400	0 000	.965	.0130	35.3	95.3	−.000003	.000717
266 800	000	.965	.0159	44.5	97.9	−.000004	.000699
0 000	00	.962	.0207	58.7	110.	−.000005	.000685
000	0	.962	.0253	73.4	112.	−.000006	.000673
00	1	.962	.0309	91.0	114.	−.000007	.000661
0	2	.962	.0377	113.	115.	−.000008	.000650

15 FEET—4.572 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00361	9.00	87.3	−.000001	.000783
1 272 000	800 000	.965	.00381	9.55	87.7	−.000001	.000779
1 192 500	750 000	.965	.00403	10.2	88.2	−.000001	.000774
1 113 000	700 000	.965	.00429	10.9	88.7	−.000001	.000770
1 033 500	650 000	.965	.00458	11.7	89.2	−.000001	.000765
954 000	600 000	.965	.00492	12.7	89.8	−.000001	.000759
874 500	550 000	.965	.00533	13.8	90.4	−.000001	.000753
795 000	500 000	.965	.00577	15.1	91.1	−.000001	.000747
715 500	450 000	.965	.00640	16.9	92.1	−.000002	.000740
636 000	400 000	.965	.00709	18.9	93.0	−.000002	.000733
556 500	350 000	.965	.00797	21.3	93.4	−.000002	.000730
477 000	300 000	.965	.00919	24.9	94.5	−.000002	.000721
397 500	250 000	.965	.0108	29.9	96.1	−.000003	.000709
336 400	0 000	.965	.0127	35.3	97.6	−.000003	.000700
266 800	000	.965	.0155	44.5	100.	−.000004	.000682
0 000	00	.962	.0202	58.7	112.	−.000005	.000670
000	0	.962	.0248	73.4	114.	−.000006	.000659
00	1	.962	.0302	91.0	116.	−.000007	.000647
0	2	.962	.0369	113.	118.	−.000008	.000636

17 FEET—5.182 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00353	9.00	89.2	−.000001	.000766
1 272 000	800 000	.965	.00372	9.55	89.7	−.000001	.000762
1 192 500	750 000	.965	.00394	10.2	90.1	−.000001	.000757
1 113 000	700 000	.965	.00419	10.9	90.6	−.000001	.000753
1 033 500	650 000	.965	.00448	11.7	91.1	−.000001	.000748
954 000	600 000	.965	.00481	12.7	91.8	−.000001	.000743
874 500	550 000	.965	.00523	13.8	92.4	−.000001	.000738
795 000	500 000	.965	.00565	15.1	93.1	−.000001	.000731
715 500	450 000	.965	.00626	16.9	94.0	−.000002	.000725
636 000	400 000	.965	.00696	18.9	94.9	−.000002	.000718
556 500	350 000	.965	.00780	21.3	95.3	−.000002	.000715
477 000	300 000	.965	.00899	24.9	96.5	−.000002	.000706
397 500	250 000	.965	.0106	29.9	98.0	−.000003	.000695
336 400	0 000	.965	.0124	35.3	99.5	−.000003	.000686
266 800	000	.965	.0152	44.5	102.	−.000003	.000670
0 000	00	.962	.0198	58.8	114.	−.000004	.000657
000	0	.962	.0243	73.4	116.	−.000005	.000646
00	1	.962	.0297	91.0	118.	−.000006	.000636
0	2	.962	.0362	113.	119.	−.000008	.000624

19 FEET—5.791 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00346	9.00	90.9	−.000001	.000750
1 272 000	800 000	.965	.00365	9.55	91.4	−.000001	.000747
1 192 500	750 000	.965	.00387	10.2	91.8	−.000001	.000743
1 113 000	700 000	.965	.00412	10.9	92.3	−.000001	.000739
1 033 500	650 000	.965	.00440	11.7	92.8	−.000001	.000734
954 000	600 000	.965	.00472	12.7	93.4	−.000001	.000729
874 500	550 000	.965	.00513	13.8	94.1	−.000001	.000724
795 000	500 000	.965	.00556	15.1	94.9	−.000001	.000718
715 500	450 000	.965	.00615	16.9	95.6	−.000001	.000712
636 000	400 000	.965	.00683	18.9	96.5	−.000002	.000706
556 500	350 000	.965	.00766	21.3	97.0	−.000002	.000702
477 000	300 000	.965	.00884	24.9	98.3	−.000002	.000694
397 500	250 000	.965	.0104	29.9	99.8	−.000002	.000684
336 400	0 000	.965	.0122	35.3	101.	−.000003	.000675
266 800	000	.965	.0150	44.5	104.	−.000003	.000658
0 000	00	.962	.0195	58.8	116.	−.000004	.000646
000	0	.962	.0239	73.4	118.	−.000005	.000636
00	1	.962	.0292	91.0	119.	−.000006	.000625
0	2	.962	.0356	113.	121.	−.000007	.000614

21 FEET—6.401 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00340	9.00	92.4	−.000001	.000738
1 272 000	800 000	.965	.00359	9.55	92.9	−.000001	.000735
1 192 500	750 000	.965	.00380	10.2	93.4	−.000001	.000730
1 113 000	700 000	.965	.00404	10.9	93.8	−.000001	.000726
1 033 500	650 000	.965	.00432	11.7	94.3	−.000001	.000721
954 000	600 000	.965	.00465	12.7	95.0	−.000001	.000717
874 500	550 000	.965	.00504	13.8	95.6	−.000001	.000712
795 000	500 000	.965	.00546	15.1	96.4	−.000001	.000706
715 500	450 000	.965	.00605	16.9	97.2	−.000001	.000700
636 000	400 000	.965	.00672	18.9	98.1	−.000002	.000694
556 500	350 000	.965	.00755	21.3	98.5	−.000002	.000691
477 000	300 000	.965	.00869	24.9	99.8	−.000002	.000682
397 500	250 000	.965	.0103	29.9	101.	−.000002	.000673
336 400	0 000	.965	.0120	35.3	103.	−.000003	.000664
266 800	000	.965	.0147	44.5	105.	−.000003	.000648
0 000	00	.962	.0192	58.8	118.	−.000004	.000637
000	0	.962	.0236	73.4	119.	−.000005	.000627
00	1	.962	.0288	91.0	121.	−.000006	.000616
0	2	.962	.0352	113.	123.	−.000007	.000606

23 FEET—7.010 METERS

Circular mils or A. W. G. (B & S.)	Copper equivalent circular mils or A. W. G.	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 351 500	850 000	.965	.00335	9.00	93.8	−.000001	.000727
1 272 000	800 000	.965	.00354	9.55	94.3	−.000001	.000724
1 192 500	750 000	.965	.00375	10.2	94.8	−.000001	.000720
1 113 000	700 000	.965	.00399	10.9	95.2	−.000001	.000716
1 033 500	650 000	.965	.00426	11.7	95.8	−.000001	.000711
954 000	600 000	.965	.00458	12.7	96.5	−.000001	.000707
874 500	550 000	.965	.00497	13.8	97.0	−.000001	.000702
795 000	500 000	.965	.00538	15.1	97.8	−.000001	.000695
715 500	450 000	.965	.00596	16.9	98.6	−.000001	.000690
636 000	400 000	.965	.00662	18.9	99.5	−.000002	.000684
556 500	350 000	.965	.00744	21.3	99.9	−.000002	.000681
477 000	300 000	.965	.00858	24.9	101.	−.000002	.000673
397 500	250 000	.965	.0101	29.9	103.	−.000002	.000663
336 400	0 000	.965	.0118	35.3	104.	−.000003	.000655
266 800	000	.965	.0146	44.5	107.	−.000003	.000640
0 000	00	.962	.0189	58.8	119.	−.000004	.000628
000	0	.962	.0232	73.4	121.	−.000005	.000618
00	1	.962	.0284	91.0	122.	−.000006	.000609
0	2	.962	.0347	113.	124.	−.000007	.000598

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

140 MILES—225.31 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.958	.005 86	12.7	91.4	-.000 002	.000 896	.958	.005 59	12.7	95.7	-.000 002	.000 855	.958	.005 39	12.7	99.0	-.000 002	.000 824
600 000	.958	.006 26	13.7	92.3	-.000 002	.000 888	.958	.005 98	13.7	96.4	-.000 002	.000 848	.958	.005 76	13.7	99.9	-.000 002	.000 818
550 000	.958	.006 74	14.9	93.0	-.000 002	.000 881	.958	.006 43	14.9	97.3	-.000 002	.000 841	.958	.006 21	14.9	101.	-.000 002	.000 812
500 000	.958	.007 31	16.3	93.8	-.000 002	.000 873	.958	.006 99	16.3	98.0	-.000 002	.000 834	.958	.006 74	16.3	101.	-.000 002	.000 805
450 000	.958	.008 01	18.0	94.6	-.000 002	.000 865	.958	.007 65	18.0	98.9	-.000 002	.000 826	.958	.007 40	18.0	102.	-.000 002	.000 798
400 000	.958	.008 88	20.2	95.9	-.000 003	.000 855	.958	.008 49	20.2	100.	-.000 002	.000 818	.958	.008 20	20.2	104.	-.000 002	.000 790
350 000	.958	.009 99	23.0	97.0	-.000 003	.000 845	.958	.009 55	23.0	101.	-.000 003	.000 808	.958	.009 23	23.0	105.	-.000 002	.000 780
300 000	.958	.011 5	26.8	98.4	-.000 003	.000 833	.958	.011 0	26.8	103.	-.000 003	.000 797	.958	.0106	26.8	106.	-.000 003	.000 771
250 000	.958	.0135	32.0	100.	-.000 004	.000 819	.958	.0129	32.0	104.	-.000 003	.000 784	.958	.0125	32.0	108.	-.000 003	.000 760
0 000	.958	.0157	37.8	102.	-.000 004	.000 807	.958	.0150	37.8	107.	-.000 004	.000 772	.958	.0145	37.8	110.	-.000 004	.000 747
000	.958	.0193	47.6	104.	-.000 005	.000 790	.958	.0185	47.6	109.	-.000 005	.000 758	.958	.0179	47.6	112.	-.000 004	.000 735
00	.958	.0239	59.9	107.	-.000 006	.000 775	.958	.0229	59.9	111.	-.000 006	.000 744	.958	.0222	59.9	114.	-.000 005	.000 721
0	.958	.0295	75.5	109.	-.000 008	.000 761	.958	.0284	75.5	113.	-.000 007	.000 731	.958	.0275	75.5	116.	-.000 007	.000 708
1	.958	.0365	95.2	111.	-.000 009	.000 746	.958	.0351	95.2	115.	-.000 009	.000 717	.958	.0341	95.2	119.	-.000 008	.000 696
2	.958	.0452	120.	114.	-.000 011	.000 732	.958	.0435	120.	118.	-.000 010	.000 704	.958	.0422	120.	121.	-.000 010	.000 684

CIRCULAR MILS OR A W G (B & S)	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.958	.005 23	12.7	102	-.000 001	.000 800	.958	.005 11	12.7	104	-.000 001	.000 782	.958	.005 00	12.7	106	-.000 001	.000 765
600 000	.958	.005 60	13.7	103	-.000 002	.000 794	.958	.005 47	13.7	105	-.000 001	.000 776	.958	.005 35	13.7	107	-.000 001	.000 760
550 000	.958	.006 03	14.9	103	-.000 002	.000 789	.958	.005 89	14.9	106	-.000 002	.000 771	.958	.005 77	14.9	108	-.000 001	.000 754
500 000	.958	.006 56	16.3	104	-.000 002	.000 783	.958	.006 40	16.3	107	-.000 002	.000 764	.958	.006 27	16.3	109	-.000 002	.000 749
450 000	.958	.007 19	18.0	105	-.000 002	.000 776	.958	.007 02	18.0	107	-.000 002	.000 758	.958	.006 88	18.0	110	-.000 002	.000 743
400 000	.958	.007 97	20.2	106	-.000 002	.000 768	.958	.007 79	20.2	109	-.000 002	.000 750	.958	.007 63	20.2	111	-.000 002	.000 735
350 000	.958	.008 98	23.0	108	-.000 002	.000 760	.958	.008 77	23.0	110	-.000 002	.000 742	.958	.008 61	23.0	112	-.000 002	.000 728
300 000	.958	.0103	26.8	109	-.000 003	.000 750	.958	.0101	26.8	111	-.000 003	.000 733	.958	.009 88	26.8	113	-.000 002	.000 718
250 000	.958	.0122	32.0	110	-.000 003	.000 739	.958	.0119	32.0	113	-.000 003	.000 722	.958	.0117	32.0	115	-.000 003	.000 708
0 000	.958	.0141	37.8	113	-.000 003	.000 728	.958	.0138	37.8	115	-.000 003	.000 713	.958	.0136	37.8	117	-.000 003	.000 699
000	.958	.0175	47.6	115	-.000 004	.000 715	.958	.0171	47.6	117	-.000 004	.000 700	.958	.0168	47.6	119	-.000 004	.000 686
00	.958	.0217	59.9	117	-.000 005	.000 703	.958	.0212	59.9	119	-.000 005	.000 688	.958	.0208	59.9	121	-.000 005	.000 675
0	.958	.0268	75.5	119	-.000 006	.000 691	.958	.0263	75.5	121	-.000 006	.000 677	.958	.0258	75.5	124	-.000 006	.000 664
1	.958	.0333	95.2	121	-.000 008	.000 679	.958	.0325	95.2	124	-.000 007	.000 664	.958	.0320	95.2	126	-.000 007	.000 653
2	.958	.0412	120.	124	-.000 009	.000 667	.958	.0404	120.	126	-.000 009	.000 655	.958	.0396	120.	128	-.000 009	.000 642

CIRCULAR MILS OR A W G (B & S)	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.959	.004 91	12.7	108	-.000 001	.000 751	.959	.004 83	12.7	110	-.000 001	.000 739	.959	.004 77	12.7	111	-.000 001	.000 729
600 000	.959	.005 26	13.7	109	-.000 001	.000 746	.959	.005 18	13.7	111	-.000 001	.000 735	.959	.005 10	13.7	112	-.000 001	.000 724
550 000	.959	.005 67	14.9	110	-.000 001	.000 742	.959	.005 58	14.9	111	-.000 001	.000 729	.959	.005 50	14.9	113	-.000 001	.000 720
500 000	.959	.006 17	16.3	111	-.000 002	.000 736	.959	.006 06	16.3	112	-.000 001	.000 724	.959	.005 98	16.3	114	-.000 001	.000 714
450 000	.959	.006 76	18.0	111	-.000 002	.000 729	.959	.006 65	18.0	113	-.000 002	.000 718	.959	.006 56	18.0	115	-.000 002	.000 708
400 000	.959	.007 50	20.2	113	-.000 002	.000 722	.959	.007 39	20.2	114	-.000 002	.000 711	.959	.007 29	20.2	116	-.000 002	.000 702
350 000	.959	.008 46	23.0	114	-.000 002	.000 715	.959	.008 33	23.0	116	-.000 002	.000 704	.959	.008 22	23.0	117	-.000 002	.000 695
300 000	.959	.009 73	26.8	115	-.000 002	.000 707	.959	.009 58	26.8	117	-.000 002	.000 696	.959	.009 44	26.8	118	-.000 002	.000 686
250 000	.959	.0115	32.0	117	-.000 003	.000 697	.959	.0113	32.0	118	-.000 003	.000 686	.959	.0112	32.0	120	-.000 003	.000 678
0 000	.958	.0134	37.8	119	-.000 003	.000 688	.958	.0131	37.8	121	-.000 003	.000 677	.958	.0130	37.8	122	-.000 003	.000 668
000	.958	.0165	47.6	121	-.000 004	.000 675	.958	.0163	47.6	123	-.000 004	.000 666	.958	.0161	47.6	124	-.000 004	.000 657
00	.958	.0205	59.9	123	-.000 005	.000 664	.958	.0202	59.9	125	-.000 004	.000 655	.958	.0199	59.9	126	-.000 004	.000 646
0	.958	.0254	75.5	125	-.000 006	.000 653	.958	.0250	75.5	127	-.000 005	.000 645	.958	.0247	75.5	129	-.000 005	.000 637
1	.958	.0315	95.2	128	-.000 007	.000 644	.958	.0310	95.2	129	-.000 007	.000 634	.958	.0307	95.2	131	-.000 007	.000 627
2	.958	.0390	120.	130	-.000 008	.000 632	.958	.0385	120.	132	-.000 008	.000 624	.958	.0381	120.	133	-.000 008	.000 617

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI. l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

140 MILES—225.31 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

Circular mils or A. W. G. (B. & S.)	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin. 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.960	.004 85	9.66	81.0	-.000 002	.000 976	.960	.004 60	9.66	85.1	-.000 001	.000 927	.960	.004 42	9.66	88.5	-.000 001	.000 891
1 272 000	800 000	.960	.005 10	10.2	81.5	-.000 002	.000 970	.960	.004 85	10.2	85.6	-.000 002	.000 921	.960	.004 67	10.2	89.0	-.000 001	.000 887
1 192 500	750 000	.960	.005 41	10.9	81.9	-.000 002	.000 964	.960	.005 13	10.9	86.2	-.000 002	.000 916	.960	.004 94	10.9	89.5	-.000 001	.000 881
1 113 000	700 000	.960	.005 74	11.7	82.5	-.000 002	.000 957	.960	.005 46	11.7	86.6	-.000 002	.000 910	.960	.005 25	11.7	90.1	-.000 002	.000 876
1 033 500	650 000	.960	.006 12	12.6	83.0	-.000 002	.000 949	.960	.005 83	12.6	87.3	-.000 002	.000 903	.960	.005 61	12.6	90.6	-.000 002	.000 869
954 000	600 000	.960	.006 57	13.6	83.7	-.000 002	.000 942	.960	.006 26	13.6	88.0	-.000 002	.000 896	.960	.006 02	13.6	91.3	-.000 002	.000 863
874 500	550 000	.960	.007 12	14.9	84.4	-.000 002	.000 934	.960	.006 78	14.9	88.6	-.000 002	.000 888	.960	.006 52	14.9	92.0	-.000 002	.000 855
795 000	500 000	.960	.007 70	16.2	85.1	-.000 002	.000 924	.960	.007 34	16.2	89.4	-.000 002	.000 881	.960	.007 06	16.2	92.7	-.000 002	.000 848
715 500	450 000	.960	.008 51	18.1	86.1	-.000 003	.000 914	.960	.008 11	18.1	90.2	-.000 002	.000 871	.960	.007 83	18.1	93.7	-.000 002	.000 841
636 000	400 000	.960	.009 44	20.3	87.1	-.000 003	.000 905	.960	.008 99	20.3	91.3	-.000 003	.000 862	.960	.008 67	20.3	94.7	-.000 002	.000 831
556 500	350 000	.960	.010 6	22.9	87.5	-.000 003	.000 900	.960	.010 1	22.9	91.8	-.000 003	.000 859	.960	.009 73	22.9	95.1	-.000 003	.000 827
477 000	300 000	.960	.012 2	26.7	88.8	-.000 004	.000 887	.960	.011 6	26.7	93.1	-.000 003	.000 847	.960	.011 2	26.7	96.5	-.000 003	.000 816
397 500	250 000	.960	.014 3	32.0	90.6	-.000 004	.000 871	.960	.013 7	32.0	94.8	-.000 004	.000 833	.960	.013 2	32.0	98.2	-.000 004	.000 804
336 400	0 000	.960	.016 7	37.9	92.1	-.000 005	.000 859	.960	.016 0	37.9	96.3	-.000 004	.000 820	.960	.015 4	37.9	99.6	-.000 004	.000 793
266 800	000	.960	.020 4	47.7	94.8	-.000 006	.000 834	.960	.019 6	47.7	99.1	-.000 005	.000 798	.960	.018 9	47.7	102.	-.000 005	.000 771
0000	00	.955	.026 5	63.0	108.	-.000 007	.000 816	.955	.025 4	63.0	112.	-.000 007	.000 782	.955	.024 6	63.0	116.	-.000 006	.000 756
000	0	.955	.032 4	78.6	110.	-.000 009	.000 800	.955	.031 1	78.6	114.	-.000 008	.000 767	.956	.030 1	78.7	117.	-.000 008	.000 742
00	1	.955	.039 4	97.5	112.	-.000 011	.000 785	.956	.037 9	97.6	116.	-.000 010	.000 754	.956	.036 6	97.6	119.	-.000 009	.000 729
0	2	.956	.048 1	121.	114.	-.000 013	.000 770	.956	.046 1	121.	118.	-.000 012	.000 738	.956	.044 8	121.	120.	-.000 011	.000 716

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.960	.004 28	9.66	91.3	-.000 001	.000 863	.960	.004 17	9.66	93.8	-.000 001	.000 841	.960	.004 09	9.66	95.9	-.000 001	.000 823
1 272 000	800 000	.960	.004 52	10.2	91.9	-.000 001	.000 859	.960	.004 41	10.2	94.2	-.000 001	.000 837	.960	.004 31	10.2	96.4	-.000 001	.000 819
1 192 500	750 000	.960	.004 79	10.9	92.3	-.000 001	.000 854	.960	.004 66	10.9	94.8	-.000 001	.000 831	.960	.004 56	10.9	96.8	-.000 001	.000 813
1 113 000	700 000	.960	.005 10	11.7	92.8	-.000 001	.000 849	.960	.004 96	11.7	95.3	-.000 001	.000 827	.960	.004 86	11.7	97.4	-.000 001	.000 809
1 033 500	650 000	.960	.005 44	12.6	93.4	-.000 002	.000 842	.960	.005 30	12.6	95.9	-.000 001	.000 822	.960	.005 19	12.6	97.9	-.000 001	.000 804
954 000	600 000	.960	.005 84	13.6	94.1	-.000 002	.000 837	.960	.005 70	13.6	96.6	-.000 002	.000 816	.960	.005 57	13.6	98.6	-.000 002	.000 798
874 500	550 000	.960	.006 33	14.9	94.8	-.000 002	.000 830	.960	.006 17	14.9	97.1	-.000 002	.000 809	.960	.006 05	14.9	99.3	-.000 002	.000 793
795 000	500 000	.960	.006 86	16.2	95.6	-.000 002	.000 823	.960	.006 68	16.2	98.0	-.000 002	.000 802	.960	.006 55	16.2	100.	-.000 002	.000 786
715 500	450 000	.960	.007 59	18.1	96.4	-.000 002	.000 815	.960	.007 41	18.1	98.9	-.000 002	.000 796	.960	.007 25	18.1	101.	-.000 002	.000 779
636 000	400 000	.960	.008 41	20.3	97.4	-.000 002	.000 807	.960	.008 21	20.3	99.9	-.000 002	.000 787	.960	.008 05	20.3	102.	-.000 002	.000 772
556 500	350 000	.960	.009 45	22.9	97.8	-.000 003	.000 804	.960	.009 22	22.9	100.	-.000 002	.000 784	.960	.009 03	22.9	102.	-.000 002	.000 768
477 000	300 000	.960	.010 9	26.7	99.3	-.000 003	.000 794	.960	.010 6	26.7	102.	-.000 003	.000 775	.960	.010 4	26.7	104.	-.000 003	.000 758
397 500	250 000	.960	.012 9	32.0	101.	-.000 003	.000 782	.960	.012 5	32.0	103.	-.000 003	.000 762	.960	.012 3	32.0	105.	-.000 003	.000 747
336 400	0 000	.960	.015 0	37.9	102.	-.000 004	.000 771	.960	.014 7	37.9	105.	-.000 004	.000 753	.960	.014 4	37.9	107.	-.000 004	.000 738
266 800	000	.960	.018 4	47.7	105.	-.000 005	.000 751	.960	.018 0	47.7	108.	-.000 004	.000 733	.960	.017 6	47.7	110.	-.000 004	.000 720
0000	00	.955	.023 9	63.0	118.	-.000 006	.000 736	.956	.023 4	63.0	121.	-.000 006	.000 720	.956	.022 9	63.1	123.	-.000 006	.000 707
000	0	.956	.029 3	78.7	120.	-.000 007	.000 723	.956	.028 7	78.7	123.	-.000 007	.000 708	.956	.028 1	78.7	125.	-.000 007	.000 694
00	1	.956	.035 7	97.6	122.	-.000 009	.000 711	.956	.034 9	97.6	124.	-.000 008	.000 696	.956	.034 3	97.6	127.	-.000 008	.000 683
0	2	.956	.043 6	121.	124.	-.000 010	.000 698	.956	.042 7	121.	127.	-.000 010	.000 683	.956	.041 9	121.	129.	-.000 010	.000 671

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.960	.004 00	9.66	97.7	-.000 001	.000 807	.960	.003 93	9.66	99.3	-.000 001	.000 793	.960	.003 88	9.66	101.	-.000 001	.000 782
1 272 000	800 000	.960	.004 22	10.2	98.2	-.000 001	.000 802	.960	.004 16	10.2	99.9	-.000 001	.000 790	.960	.004 09	10.2	101.	-.000 001	.000 778
1 192 500	750 000	.960	.004 48	10.9	98.6	-.000 001	.000 798	.960	.004 40	10.9	100.	-.000 001	.000 784	.960	.004 34	10.9	102.	-.000 001	.000 773
1 113 000	700 000	.960	.004 76	11.7	99.2	-.000 001	.000 794	.960	.004 68	11.7	101.	-.000 001	.000 780	.960	.004 61	11.7	102.	-.000 001	.000 769
1 033 500	650 000	.960	.005 09	12.6	99.7	-.000 001	.000 789	.960	.005 00	12.6	101.	-.000 001	.000 775	.960	.004 93	12.6	103.	-.000 001	.000 764
954 000	600 000	.960	.005 47	13.6	100.	-.000 001	.000 783	.960	.005 38	13.6	102.	-.000 001	.000 771	.960	.005 30	13.6	104.	-.000 001	.000 760
874 500	550 000	.960	.005 93	14.9	101.	-.000 002	.000 778	.960	.005 84	14.9	103.	-.000 002	.000 765	.960	.005 75	14.9	104.	-.000 001	.000 754
795 000	500 000	.960	.006 43	16.2	102.	-.000 002	.000 772	.960	.006 32	16.2	104.	-.000 002	.000 758	.960	.006 22	16.2	105.	-.000 002	.000 747
715 500	450 000	.960	.007 12	18.1	103.	-.000 002	.000 765	.960	.007 01	18.1	104.	-.000 002	.000 753	.960	.006 90	18.1	106.	-.000 002	.000 742
636 000	400 000	.960	.007 91	20.3	104.	-.000 002	.000 758	.960	.007 78	20.3	106.	-.000 002	.000 746	.960	.007 66	20.3	107.	-.000 002	.000 735
556 500	350 000	.960	.008 87	22.9	104.	-.000 002	.000 754	.960	.008 74	22.9	106.	-.000 002	.000 743	.960	.008 61	22.9	107.	-.000 002	.000 732
477 000	300 000	.960	.010 2	26.7	106.	-.000 003	.000 746	.960	.010 1	26.7	107.	-.000 003	.000 733	.960	.009 93	26.7	109.	-.000 002	.000 724
397 500	250 000	.960	.012 1	32.0	107.	-.000 003	.000 735	.960	.011 9	32.0	109.	-.000 003	.000 724	.960	.011 7	32.0	110.	-.000 003	.000 713
336 400	0 000	.960	.014 1	37.9	109.	-.000 003	.000 725	.960	.013 9	37.9	111.	-.000 003	.000 714	.960	.013 7	37.9	112.	-.000 003	.000 704
266 800	000	.960	.017 3	47.7	112.	-.000 004	.000 707	.960	.017 1	47.7	113.	-.000 004	.000 696	.960	.016 9	47.7	115.	-.000 004	.000 688
0000	00	.956	.022 5	63.1	125.	-.000 005	.000 694	.956	.022 2	63.1	127.	-.000 005	.000 685	.956	.021 9	63.1	128.	-.000 005	.000 675
000	0	.956	.027 7	78.7	126.	-.000 006	.000 683	.956	.027 3	78.7	128.	-.000 006	.000 673	.956	.026 9	78.7	130.	-.000 006	.000 664
00	1	.956	.033 8	97.6	128.	-.000 008	.000 672	.956	.033 3	97.6	130.	-.000 007	.000 662	.956	.032 9	97.6	132.	-.000 007	.000 654
0	2	.956	.041 2	121.	130.	-.000 009	.000 660	.956	.040 7	121.	132.	-.000 009	.000 651	.956	.040 2	121.	134.	-.000 009	.000 643

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40,320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

150 MILES—241.40 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.952	.006 71	13.6	97.7	-.000 002	.000 958	.952	.006 40	13.6	102	-.000 002	.000 914	.952	.006 17	13.6	106	-.000 002	.000 881
600 000	.952	.007 17	14.6	98.6	-.000 002	.000 949	.952	.006 84	14.6	103	-.000 002	.000 906	.952	.006 60	14.6	107	-.000 002	.000 874
550 000	.952	.007 72	15.9	99.4	-.000 002	.000 942	.952	.007 37	15.9	104	-.000 002	.000 899	.952	.007 11	15.9	107	-.000 002	.000 868
500 000	.952	.008 37	17.4	100.	-.000 003	.000 933	.952	.008 00	17.4	105	-.000 002	.000 892	.952	.007 73	17.4	108	-.000 002	.000 861
450 000	.952	.009 17	19.2	101.	-.000 003	.000 924	.952	.008 77	19.2	106	-.000 003	.000 883	.952	.008 47	19.2	109	-.000 002	.000 853
400 000	.952	.010 2	21.5	103.	-.000 003	.000 914	.952	.009 72	21.5	107	-.000 003	.000 874	.952	.009 40	21.5	111	-.000 003	.000 844
350 000	.952	.011 4	24.5	104.	-.000 004	.000 903	.952	.010 9	24.5	108	-.000 003	.000 863	.952	.010 6	24.5	112	-.000 003	.000 834
300 000	.952	.013 1	28.5	105.	-.000 004	.000 890	.952	.012 6	28.5	110	-.000 004	.000 852	.952	.012 1	28.5	113	-.000 003	.000 824
250 000	.952	.015 5	34.2	107.	-.000 005	.000 875	.952	.014 8	34.2	111	-.000 004	.000 838	.952	.014 3	34.2	115	-.000 004	.000 812
0000	.952	.017 9	40.3	109.	-.000 005	.000 862	.952	.017 2	40.3	114	-.000 005	.000 825	.952	.016 6	40.3	118	-.000 005	.000 799
000	.952	.022 1	50.7	112.	-.000 006	.000 844	.952	.021 2	50.7	116	-.000 006	.000 810	.952	.020 5	50.7	120	-.000 005	.000 784
00	.952	.027 3	63.9	114.	-.000 008	.000 828	.952	.026 3	63.9	118	-.000 007	.000 796	.952	.025 4	63.9	122	-.000 007	.000 770
0	.952	.033 8	80.6	116.	-.000 009	.000 813	.952	.032 5	80.6	121	-.000 009	.000 781	.952	.031 5	80.6	124	-.000 008	.000 757
1	.952	.041 8	102.	119.	-.000 011	.000 797	.952	.040 2	102.	123	-.000 011	.000 766	.952	.039 0	102.	127	-.000 010	.000 744
2	.952	.051 7	128.	122.	-.000 014	.000 782	.952	.049 8	128.	126	-.000 013	.000 753	.952	.048 3	128.	130	-.000 012	.000 731

CIRCULAR MILS OR A. W. G. (B & S)	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.952	.005 99	13.6	109	-.000 002	.000 855	.952	.005 85	13.6	111	-.000 002	.000 835	.952	.005 73	13.6	114	-.000 002	.000 818
600 000	.952	.006 41	14.6	110	-.000 002	.000 849	.952	.006 26	14.6	112	-.000 002	.000 830	.952	.006 13	14.6	114	-.000 002	.000 812
550 000	.952	.006 91	15.9	110	-.000 002	.000 843	.952	.006 75	15.9	113	-.000 002	.000 824	.952	.006 61	15.9	115	-.000 002	.000 806
500 000	.952	.007 51	17.4	111	-.000 002	.000 837	.952	.007 33	17.4	114	-.000 002	.000 816	.952	.007 18	17.4	116	-.000 002	.000 800
450 000	.952	.008 24	19.2	112	-.000 002	.000 830	.952	.008 05	19.2	115	-.000 002	.000 810	.952	.007 89	19.2	117	-.000 002	.000 794
400 000	.952	.009 13	21.5	114	-.000 003	.000 821	.952	.008 92	21.5	116	-.000 002	.000 801	.952	.008 74	21.5	118	-.000 002	.000 785
350 000	.952	.010 3	24.5	115	-.000 003	.000 812	.952	.010 0	24.5	117	-.000 003	.000 793	.952	.009 86	24.5	120	-.000 003	.000 778
300 000	.952	.011 8	28.5	116	-.000 003	.000 801	.952	.011 6	28.5	119	-.000 003	.000 784	.952	.011 3	28.5	121	-.000 003	.000 768
250 000	.952	.013 9	34.2	118	-.000 004	.000 790	.952	.013 6	34.2	120	-.000 004	.000 772	.952	.013 4	34.2	123	-.000 003	.000 757
0000	.952	.016 2	40.3	121	-.000 004	.000 778	.952	.015 9	40.3	123	-.000 004	.000 762	.952	.015 6	40.3	125	-.000 004	.000 747
000	.952	.020 0	50.7	123	-.000 005	.000 765	.952	.019 6	50.7	125	-.000 005	.000 748	.952	.019 2	50.7	127	-.000 005	.000 734
00	.952	.024 8	63.9	125	-.000 006	.000 751	.952	.024 3	63.9	127	-.000 006	.000 735	.952	.023 8	63.9	130	-.000 006	.000 722
0	.952	.030 7	80.6	127	-.000 008	.000 738	.952	.030 1	80.6	130	-.000 007	.000 723	.952	.029 5	80.6	132	-.000 007	.000 710
1	.952	.038 1	102.	130	-.000 009	.000 726	.952	.037 3	102.	132	-.000 009	.000 710	.952	.036 6	102.	135	-.000 009	.000 698
2	.952	.047 2	128.	133	-.000 011	.000 713	.952	.046 3	128.	135	-.000 011	.000 700	.952	.045 4	128.	138	-.000 011	.000 686

CIRCULAR MILS OR A. W. G. (B & S)	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.952	.005 63	13.6	116	-.000 002	.000 803	.952	.005 53	13.6	117	-.000 001	.000 790	.952	.005 46	13.6	119	-.000 001	.000 779
600 000	.952	.006 02	14.6	116	-.000 002	.000 797	.952	.005 93	14.6	118	-.000 002	.000 785	.952	.005 84	14.6	120	-.000 002	.000 773
550 000	.952	.006 50	15.9	117	-.000 002	.000 793	.952	.006 39	15.9	119	-.000 002	.000 779	.952	.006 30	15.9	121	-.000 002	.000 769
500 000	.952	.007 06	17.4	118	-.000 002	.000 787	.952	.006 94	17.4	120	-.000 002	.000 773	.952	.006 85	17.4	122	-.000 002	.000 763
450 000	.952	.007 74	19.2	119	-.000 002	.000 779	.952	.007 62	19.2	121	-.000 002	.000 768	.952	.007 52	19.2	123	-.000 002	.000 757
400 000	.952	.008 59	21.5	121	-.000 002	.000 772	.952	.008 46	21.5	122	-.000 002	.000 760	.952	.008 35	21.5	124	-.000 002	.000 750
350 000	.952	.009 69	24.5	122	-.000 003	.000 765	.952	.009 54	24.5	123	-.000 002	.000 753	.952	.009 41	24.5	125	-.000 002	.000 742
300 000	.952	.011 1	28.5	123	-.000 003	.000 756	.952	.011 0	28.5	125	-.000 003	.000 744	.952	.010 8	28.5	126	-.000 003	.000 734
250 000	.952	.013 2	34.2	125	-.000 003	.000 745	.952	.013 0	34.2	127	-.000 003	.000 734	.952	.012 8	34.2	128	-.000 003	.000 725
0000	.952	.015 3	40.3	127	-.000 004	.000 735	.952	.015 1	40.3	129	-.000 004	.000 723	.952	.014 9	40.3	131	-.000 004	.000 714
000	.952	.018 9	50.7	129	-.000 005	.000 722	.952	.018 7	50.7	131	-.000 005	.000 711	.952	.018 4	50.7	133	-.000 004	.000 703
00	.952	.023 4	63.9	132	-.000 006	.000 710	.952	.023 1	63.9	134	-.000 006	.000 700	.952	.022 8	63.9	135	-.000 005	.000 691
0	.952	.029 1	80.6	134	-.000 007	.000 698	.952	.028 7	80.6	136	-.000 007	.000 689	.952	.028 3	80.6	137	-.000 007	.000 680
1	.952	.036 1	102.	137	-.000 008	.000 688	.952	.035 5	102.	138	-.000 008	.000 677	.952	.035 2	102.	140	-.000 008	.000 670
2	.952	.044 7	128.	139	-.000 010	.000 676	.952	.044 1	128.	141	-.000 010	.000 667	.952	.043 6	128.	143	-.000 010	.000 660

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

150 MILES—241.40 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.954	.00555	10.3	86.6	-.000002	.001044	.954	.00527	10.3	91.0	-.000002	.000991	.954	.00506	10.3	94.7	-.000002	.000953
1 272 000	800 000	.954	.00584	10.9	87.2	-.000002	.001037	.954	.00555	10.9	91.6	-.000002	.000985	.954	.00535	10.9	95.1	-.000002	.000948
1 192 500	750 000	.954	.00619	11.6	87.6	-.000002	.001031	.954	.00588	11.6	92.2	-.000002	.000979	.954	.00566	11.6	95.7	-.000002	.000942
1 113 000	700 000	.954	.00657	12.5	88.2	-.000002	.001024	.954	.00625	12.5	92.6	-.000002	.000973	.954	.00601	12.5	96.3	-.000002	.000936
1 033 500	650 000	.954	.00701	13.4	88.8	-.000002	.001015	.954	.00668	13.4	93.4	-.000002	.000966	.954	.00642	13.4	96.9	-.000002	.000929
954 000	600 000	.954	.00753	14.5	89.6	-.000003	.001007	.954	.00716	14.5	94.1	-.000002	.000959	.954	.00690	14.5	97.7	-.000002	.000923
874 500	550 000	.954	.00816	15.8	90.3	-.000003	.000999	.954	.00776	15.8	94.7	-.000003	.000950	.954	.00747	15.8	98.4	-.000002	.000914
795 000	500 000	.954	.00881	17.3	91.0	-.000003	.000988	.954	.00840	17.3	95.6	-.000003	.000942	.954	.00809	17.3	99.2	-.000002	.000907
715 500	450 000	.954	.00975	19.3	92.1	-.000003	.000978	.954	.00929	19.3	96.5	-.000003	.000932	.954	.00897	19.3	100.	-.000003	.000900
636 000	400 000	.954	.0108	21.7	93.1	-.000004	.000967	.954	.0103	21.7	97.7	-.000003	.000922	.954	.00993	21.7	101.	-.000003	.000889
556 500	350 000	.954	.0121	24.4	93.6	-.000004	.000963	.954	.0116	24.4	98.2	-.000004	.000919	.954	.0111	24.4	102.	-.000003	.000885
477 000	300 000	.954	.0139	28.5	95.0	-.000004	.000948	.954	.0133	28.5	99.5	-.000004	.000905	.954	.0128	28.5	103.	-.000004	.000873
397 500	250 000	.954	.0164	34.2	96.9	-.000005	.000932	.954	.0157	34.2	101.	-.000005	.000891	.954	.0151	34.2	105.	-.000004	.000860
336 400	0000	.954	.0191	40.4	98.5	-.000006	.000919	.954	.0183	40.4	103.	-.000005	.000877	.954	.0177	40.4	107.	-.000005	.000848
266 800	000	.954	.0234	50.9	101.	-.000007	.000892	.954	.0224	50.9	106.	-.000007	.000854	.954	.0216	50.9	110.	-.000006	.000824
0000	00	.948	.0304	67.2	116.	-.000009	.000873	.949	.0291	67.2	120.	-.000008	.000836	.949	.0281	67.2	124.	-.000008	.000808
000	0	.949	.0371	83.8	118.	-.000011	.000855	.949	.0356	83.8	122.	-.000010	.000820	.949	.0345	83.9	126.	-.000009	.000794
00	1	.949	.0452	104.	120.	-.000013	.000839	.949	.0434	104.	124.	-.000012	.000805	.949	.0419	104.	128.	-.000011	.000779
0	2	.949	.0551	129.	122.	-.000015	.000823	.949	.0528	129.	127.	-.000014	.000789	.949	.0513	129.	130.	-.000013	.000766

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.954	.00491	10.3	97.7	-.000002	.000923	.954	.00478	10.3	100	-.000001	.000900	.954	.00468	10.3	103	-.000001	.000880
1 272 000	800 000	.954	.00518	10.9	98.2	-.000002	.000919	.954	.00505	10.9	101	-.000002	.000895	.954	.00494	10.9	103	-.000001	.000876
1 192 500	750 000	.954	.00548	11.6	98.7	-.000002	.000913	.954	.00534	11.6	101	-.000002	.000889	.954	.00522	11.6	104	-.000002	.000870
1 113 000	700 000	.954	.00584	12.5	99.3	-.000002	.000908	.954	.00568	12.5	102	-.000002	.000885	.954	.00556	12.5	104	-.000002	.000866
1 033 500	650 000	.954	.00623	13.4	99.9	-.000002	.000901	.954	.00607	13.4	103	-.000002	.000879	.954	.00594	13.4	105	-.000002	.000860
954 000	600 000	.954	.00669	14.5	101.	-.000002	.000895	.954	.00652	14.5	103	-.000002	.000873	.954	.00638	14.5	106	-.000002	.000854
874 500	550 000	.954	.00725	15.8	101.	-.000002	.000888	.954	.00707	15.8	104	-.000002	.000866	.954	.00693	15.8	106	-.000002	.000848
795 000	500 000	.954	.00785	17.3	102.	-.000002	.000880	.954	.00765	17.3	105	-.000002	.000858	.954	.00750	17.3	107	-.000002	.000840
715 500	450 000	.954	.00869	19.3	103.	-.000003	.000871	.954	.00848	19.3	106	-.000002	.000851	.954	.00830	19.3	108	-.000002	.000833
636 000	400 000	.954	.00963	21.7	104.	-.000003	.000863	.954	.00940	21.7	107	-.000003	.000842	.954	.00922	21.7	109	-.000003	.000826
556 500	350 000	.954	.0108	24.4	105.	-.000003	.000860	.954	.0106	24.4	107	-.000003	.000839	.954	.0103	24.4	110	-.000003	.000821
477 000	300 000	.954	.0125	28.5	106.	-.000004	.000849	.954	.0122	28.5	109	-.000003	.000829	.954	.0119	28.5	111	-.000003	.000811
397 500	250 000	.954	.0147	34.2	108.	-.000004	.000836	.954	.0144	34.2	111	-.000004	.000815	.954	.0141	34.2	113	-.000004	.000799
336 400	0000	.954	.0172	40.4	110.	-.000005	.000824	.954	.0168	40.4	112	-.000005	.000805	.954	.0164	40.4	114	-.000004	.000789
266 800	000	.954	.0211	50.9	113.	-.000006	.000804	.954	.0206	50.9	115	-.000006	.000784	.954	.0202	50.9	117	-.000005	.000770
0000	00	.949	.0274	67.2	127.	-.000007	.000787	.949	.0268	67.2	129	-.000007	.000769	.949	.0263	67.2	132	-.000007	.000755
000	0	.949	.0336	83.9	129.	-.000009	.000773	.949	.0329	83.9	131	-.000008	.000757	.949	.0322	83.9	133	-.000008	.000742
00	1	.949	.0409	104.	131.	-.000011	.000760	.950	.0400	104.	133	-.000010	.000743	.950	.0393	104.	135	-.000010	.000730
0	2	.950	.0500	129.	133.	-.000013	.000746	.950	.0489	129.	136	-.000012	.000730	.950	.0480	129.	138	-.000012	.000717

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.954	.00458	10.3	104	-.000001	.000863	.954	.00451	10.3	106	-.000001	.000848	.954	.00444	10.3	108	-.000001	.000836
1 272 000	800 000	.954	.00484	10.9	105	-.000001	.000858	.954	.00476	10.9	107	-.000001	.000845	.954	.00469	10.9	108	-.000001	.000832
1 192 500	750 000	.954	.00513	11.6	106	-.000001	.000854	.954	.00504	11.6	107	-.000001	.000839	.954	.00497	11.6	109	-.000001	.000827
1 113 000	700 000	.954	.00546	12.5	106	-.000002	.000849	.954	.00536	12.5	108	-.000002	.000835	.954	.00528	12.5	109	-.000001	.000823
1 033 500	650 000	.954	.00583	13.4	107	-.000002	.000843	.954	.00573	13.4	108	-.000002	.000829	.954	.00565	13.4	110	-.000002	.000817
954 000	600 000	.954	.00626	14.5	107	-.000002	.000838	.954	.00616	14.5	109	-.000002	.000824	.954	.00607	14.5	111	-.000002	.000812
874 500	550 000	.954	.00679	15.8	108	-.000002	.000832	.954	.00669	15.8	110	-.000002	.000818	.954	.00659	15.8	112	-.000002	.000806
795 000	500 000	.954	.00736	17.3	109	-.000002	.000826	.954	.00723	17.3	111	-.000002	.000811	.954	.00713	17.3	112	-.000002	.000799
715 500	450 000	.954	.00816	19.3	110	-.000002	.000818	.954	.00803	19.3	112	-.000002	.000805	.954	.00791	19.3	113	-.000002	.000793
636 000	400 000	.954	.00906	21.7	111	-.000003	.000811	.954	.00891	21.7	113	-.000002	.000798	.954	.00878	21.7	114	-.000002	.000786
556 500	350 000	.954	.0102	24.4	112	-.000003	.000806	.954	.0100	24.4	113	-.000003	.000795	.954	.00986	24.4	115	-.000003	.000783
477 000	300 000	.954	.0117	28.5	113	-.000003	.000798	.954	.0115	28.5	115	-.000003	.000784	.954	.0114	28.5	116	-.000003	.000774
397 500	250 000	.954	.0138	34.2	115	-.000004	.000786	.954	.0136	34.2	117	-.000004	.000774	.954	.0134	34.2	118	-.000003	.000762
336 400	0000	.954	.0162	40.4	116	-.000004	.000775	.954	.0159	40.4	118	-.000004	.000764	.954	.0157	40.4	120	-.000004	.000753
266 800	000	.954	.0198	50.9	119	-.000005	.000756	.954	.0195	50.9	121	-.000005	.000744	.954	.0193	50.9	123	-.000005	.000736
0000	00	.949	.0258	67.2	134	-.000007	.000742	.949	.0255	67.2	135	-.000006	.000732	.949	.0251	67.2	137	-.000006	.000721
000	0	.950	.0317	83.9	135	-.000008	.000730	.950	.0313	83.9	137	-.000008	.000720	.950	.0308	83.9	139	-.000007	.000710
00	1	.950	.0387	104.	137	-.000009	.000718	.950	.0381	104.	139	-.000009	.000708	.950	.0376	104.	141	-.000009	.000699
0	2	.950	.0472	129.	140	-.000011	.000705	.950	.0466	129.	141	-.000011	.000696	.950	.0460	129.	143	-.000011	.000687

$$A = \cosh\theta = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40{,}320}+\right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

160 MILES—257.50 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.946	.007 62	14.4	104	−.000 003	.001 020	.946	.007 27	14.4	109	−.000 002	.000 972	.946	.007 01	14.4	113	−.000 002	.000 938
600 000	.946	.008 14	15.5	105	−.000 003	.001 010	.946	.007 77	15.5	110	−.000 003	.000 965	.946	.007 49	15.5	114	−.000 002	.000 930
550 000	.946	.008 77	16.9	106	−.000 003	.001 002	.946	.008 37	16.9	111	−.000 003	.000 957	.946	.008 08	16.9	114	−.000 003	.000 924
500 000	.946	.009 51	18.5	107	−.000 003	.000 993	.946	.009 09	18.5	111	−.000 003	.000 949	.946	.008 77	18.5	115	−.000 003	.000 916
450 000	.946	.0104	20.4	108	−.000 004	.000 983	.946	.009 95	20.4	113	−.000 003	.000 939	.946	.009 62	20.4	116	−.000 003	.000 908
400 000	.946	.0115	22.9	109	−.000 004	.000 972	.946	.0110	22.9	114	−.000 004	.000 930	.946	.0107	22.9	118	−.000 003	.000 899
350 000	.946	.0130	26.1	110	−.000 004	.000 961	.946	.0124	26.1	115	−.000 004	.000 919	.946	.0120	26.1	119	−.000 004	.000 888
300 000	.946	.0149	30.3	112	−.000 005	.000 947	.946	.0143	30.3	117	−.000 004	.000 906	.946	.0138	30.3	121	−.000 004	.000 877
250 000	.946	.0175	36.3	114	−.000 006	.000 932	.946	.0168	36.3	119	−.000 005	.000 892	.946	.0163	36.3	122	−.000 005	.000 864
0 000	.945	.0204	42.8	117	−.000 006	.000 917	.945	.0195	42.8	121	−.000 006	.000 878	.945	.0189	42.8	125	−.000 005	.000 850
000	.945	.0251	53.9	119	−.000 008	.000 899	.945	.0241	53.9	124	−.000 007	.000 862	.945	.0233	53.9	128	−.000 007	.000 834
00	.945	.0310	67.9	121	−.000 009	.000 881	.945	.0298	67.9	126	−.000 009	.000 847	.945	.0289	67.9	130	−.000 008	.000 820
0	.945	.0384	85.6	124	−.000 011	.000 866	.945	.0369	85.6	129	−.000 010	.000 831	.945	.0358	85.6	133	−.000 010	.000 806
1	.945	.0475	108.	127	−.000 014	.000 848	.945	.0456	108.	131	−.000 013	.000 815	.945	.0443	108.	135	−.000 012	.000 792
2	.945	.0588	136.	130	−.000 017	.000 833	.945	.0565	136.	135	−.000 015	.000 801	.945	.0549	136.	138	−.000 015	.000 778

	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.946	.006 80	14.4	116	−.000 002	.000 910	.946	.006 65	14.4	119	−.000 002	.000 889	946	.006 51	14.4	121	−.000 002	.000 870
600 000	.946	.007 28	15.5	117	−.000 002	.000 903	.946	.007 11	15.5	119	−.000 002	.000 883	946	.006 96	15.5	122	−.000 002	.000 864
550 000	.946	.007 84	16.9	118	−.000 002	.000 897	.946	.007 67	16.9	120	−.000 002	.000 877	946	.007 50	16.9	123	−.000 002	.000 858
500 000	.946	.008 53	18.5	119	−.000 003	.000 891	.946	.008 32	18.5	121	−.000 002	.000 869	946	.008 16	18.5	124	−.000 002	.000 851
450 000	.946	.009 35	20.4	119	−.000 003	.000 883	.946	.009 14	20.4	122	−.000 003	.000 862	946	.008 95	20.4	125	−.000 003	.000 845
400 000	.946	.0104	22.9	121	−.000 003	.000 873	.946	.0101	22.9	124	−.000 003	.000 853	946	.009 92	22.9	126	−.000 003	.000 836
350 000	.946	.0117	26.1	122	−.000 003	.000 864	.946	.0114	26.1	125	−.000 003	.000 844	946	.0112	26.1	127	−.000 003	.000 828
300 000	.946	.0134	30.3	124	−.000 004	.000 853	.946	.0131	30.3	126	−.000 004	.000 834	946	.0128	30.3	129	−.000 004	.000 817
250 000	.946	.0158	36.3	126	−.000 005	.000 840	.946	.0155	36.3	128	−.000 004	.000 822	946	.0152	36.3	131	−.000 004	.000 806
0 000	.945	.0184	42.8	128	−.000 005	.000 828	.945	.0180	42.8	131	−.000 005	.000 811	946	.0177	42.8	133	−.000 005	.000 795
000	.945	.0228	53.9	131	−.000 006	.000 814	.945	.0223	53.9	133	−.000 006	.000 796	946	.0218	53.9	136	−.000 006	.000 781
00	.945	.0282	67.9	133	−.000 008	.000 800	.945	.0276	67.9	136	−.000 007	.000 782	946	.0271	67.9	138	−.000 007	.000 768
0	.945	.0349	85.6	136	−.000 009	.000 786	.945	.0342	85.6	138	−.000 009	.000 770	946	.0335	85.6	141	−.000 009	.000 756
1	.945	.0433	108.	138	−.000 011	.000 773	.945	.0423	108.	141	−.000 011	.000 756	946	.0416	108.	144	−.000 011	.000 743
2	.945	.0535	136.	142	−.000 014	.000 759	.945	.0525	136.	144	−.000 013	.000 745	946	.0515	136.	147	−.000 013	.000 731

	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.946	.006 39	14.4	123	−.000 002	.000 855	.946	.006 28	14.4	125	−.000 002	.000 840	.946	.006 20	14.4	127	−.000 002	.000 829
600 000	.946	.006 84	15.5	124	−.000 002	.000 848	.946	.006 73	15.5	126	−.000 002	.000 836	.946	.006 63	15.5	128	−.000 002	.000 823
550 000	.946	.007 38	16.9	125	−.000 002	.000 844	.946	.007 25	16.9	127	−.000 002	.000 829	.946	.007 16	16.9	128	−.000 002	.000 818
500 000	.946	.008 02	18.5	126	−.000 002	.000 837	.946	.007 88	18.5	128	−.000 002	.000 823	.946	.007 78	18.5	129	−.000 002	.000 812
450 000	.946	.008 79	20.4	127	−.000 002	.000 829	.946	.008 65	20.4	129	−.000 002	.000 817	.946	.008 54	20.4	130	−.000 002	.000 806
400 000	.946	.009 76	22.9	128	−.000 003	.000 822	.946	.009 61	22.9	130	−.000 003	.000 809	.946	.009 48	22.9	132	−.000 003	.000 798
350 000	.946	.0110	26.1	130	−.000 003	.000 814	.946	.0108	26.1	131	−.000 003	.000 801	.946	.0107	26.1	133	−.000 003	.000 790
300 000	.946	.0127	30.3	131	−.000 003	.000 804	.946	.0125	30.3	133	−.000 003	.000 792	.946	.0123	30.3	135	−.000 003	.000 781
250 000	.946	.0149	36.3	133	−.000 004	.000 793	.946	.0147	36.3	135	−.000 004	.000 781	.946	.0145	36.3	136	−.000 004	.000 771
0 000	.946	.0174	42.8	136	−.000 005	.000 782	.946	.0171	42.8	137	−.000 005	.000 770	.946	.0169	42.8	139	−.000 004	.000 760
000	.946	.0215	53.9	138	−.000 006	.000 768	.946	.0212	53.9	140	−.000 005	.000 757	.946	.0209	53.9	141	−.000 005	.000 748
00	.946	.0266	67.9	140	−.000 007	.000 756	.946	.0262	67.9	142	−.000 007	.000 745	.946	.0259	67.9	144	−.000 007	.000 735
0	.946	.0330	85.6	143	−.000 008	.000 743	.946	.0326	85.6	145	−.000 008	.000 734	.946	.0322	85.6	146	−.000 008	.000 724
1	.946	.0410	108.	146	−.000 010	.000 732	.946	.0404	108.	147	−.000 010	.000 721	.946	.0399	108.	149	−.000 010	.000 713
2	.946	.0508	136.	149	−.000 012	.000 720	.946	.0501	136.	151	−.000 012	.000 710	.946	.0496	136.	152	−.000 012	.000 702

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing

Symmetrical triangular spacing

Irregular flat spacing

Regular flat spacing

TABLE LXVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

160 MILES—257.50 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.947	.006 30	11.0	92.1	−.000 002	.001 111	.948	.005 98	11.0	96.9	−000 002	.001 055	.948	.005 75	11.0	101	−.000 002	.001 014
1 272 000	800 000	.947	.006 64	11.6	92.8	−.000 003	.001 104	.948	.006 31	11.6	97.5	−000 002	.001 049	.948	.006 07	11.6	101	−.000 002	.001 009
1 192 500	750 000	.947	.007 03	12.4	93.3	−.000 003	.001 097	.948	.006 68	12.4	98.1	−000 002	.001 042	.948	.006 42	12.4	102	−.000 002	.001 003
1 113 000	700 000	.948	.007 47	13.2	93.9	−.000 003	.001 089	.948	.007 10	13.2	98.6	−000 003	.001 036	.948	.006 83	13.2	103	−.000 002	.000 997
1 033 500	650 000	.948	.007 96	14.2	94.5	−.000 003	.001 080	.948	.007 58	14.2	99.4	−000 003	.001 028	.948	.007 29	14.2	103	−.000 002	.000 989
954 000	600 000	.948	.008 55	15.4	95.3	−.000 003	.001 072	.948	.008 13	15.4	100.	−000 003	.001 020	.948	.007 83	15.4	104	−.000 003	.000 983
874 500	550 000	.948	.009 76	16.8	96.1	−.000 003	.001 063	.948	.008 81	16.8	101.	−000 003	.001 011	.948	.008 48	16.8	105	−.000 003	.000 973
795 000	500 000	.948	.0100	18.4	96.9	−.000 004	.001 052	.948	.009 54	18.4	102.	−000 003	.001 003	.948	.009 19	18.4	106	−.000 003	.000 965
715 500	450 000	.948	.011 1	20.5	98.0	−.000 004	.001 041	.948	.010 6	20.5	103.	−000 004	.000 992	.948	.010 2	20.5	107	−.000 003	.000 957
636 000	400 000	.948	.012 3	23.0	99.1	−.000 004	.001 030	.948	.011 7	23.0	104.	−000 004	.000 981	.948	.011 3	23.0	108	−.000 004	.000 946
556 500	350 000	.948	.013 8	25.9	99.6	−.000 005	.001 025	.948	.013 1	25.9	105.	−000 004	.000 978	.948	.012 7	25.9	108	−.000 004	.000 942
477 000	300 000	.948	.015 8	30.3	101.	−.000 005	.001 009	.948	.015 1	30.3	106.	−000 005	.000 964	.948	.014 6	30.3	110	−.000 005	.000 929
397 500	250 000	.948	.018 6	36.3	103.	−.000 006	.000 992	.948	.017 8	36.3	108.	−000 006	.000 948	.948	.017 2	36.3	112	−.000 005	.000 915
336 400	0 000	.947	.021 7	42.9	105.	−.000 007	.000 978	.947	.020 8	42.9	110.	−000 007	.000 934	.948	.020 1	42.9	114	−.000 006	.000 902
266 800	000	.947	.026 6	54.0	108.	−.000 009	.000 950	.947	.025 4	54.0	113.	−000 008	.000 909	.948	.024 6	54.0	117	−.000 007	.000 877
0000	00	.941	.034 5	71.4	123.	−.000 011	.000 929	.942	.033 0	71.4	128.	−000 010	.000 890	.942	.031 9	71.4	132	−.000 009	.000 860
000	0	.941	.042 1	89.1	125.	−.000 013	.000 910	.942	.040 4	89.1	130.	−000 012	.000 872	.942	.039 1	89.1	134	−.000 011	.000 844
00	1	.942	.051 3	110.	128.	−.000 016	.000 893	.942	.049 2	111.	132.	−000 014	.000 857	.942	.047 6	111.	136	−.000 014	.000 828
0	2	.942	.062 5	137.	130.	−.000 019	.000 876	.942	.060 0	137.	135.	−000 017	.000 839	.942	.058 2	137.	139	−.000 016	.000 814

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.948	.005 57	11.0	104	−.000 002	.000 983	.948	.005 43	11.0	107	−.000 002	.000 957	.948	.005 31	11.0	109	−.000 002	.000 937
1 272 000	800 000	.948	.005 88	11.6	105	−.000 002	.000 978	.948	.005 73	11.6	107	−.000 002	.000 953	.948	.005 61	11.6	110	−.000 002	.000 932
1 192 500	750 000	.948	.006 22	12.4	105	−.000 002	.000 972	.948	.006 06	12.4	108	−.000 002	.000 946	.948	.005 93	12.4	110	−.000 002	.000 926
1 113 000	700 000	.948	.006 63	13.2	106	−.000 002	.000 967	.948	.006 45	13.2	109	−.000 002	.000 942	.948	.006 31	13.2	111	−.000 002	.000 921
1 033 500	650 000	.948	.007 07	14.2	106	−.000 002	.000 959	.948	.006 90	14.2	109	−.000 002	.000 935	.948	.006 75	14.2	112	−.000 002	.000 915
954 000	600 000	.948	.007 60	15.4	107	−.000 002	.000 953	.948	.007 41	15.4	110	−.000 002	.000 929	.948	.007 24	15.4	112	−.000 002	.000 909
874 500	550 000	.948	.008 24	16.8	108	−.000 003	.000 945	.948	.008 03	16.8	111	−.000 003	.000 921	.948	.007 87	16.8	113	−.000 002	.000 902
795 000	500 000	.948	.008 92	18.4	109	−.000 003	.000 937	.948	.008 69	18.4	112	−.000 003	.000 913	.948	.008 51	18.4	114	−.000 003	.000 895
715 500	450 000	.948	.009 86	20.5	110	−.000 003	.000 928	.948	.009 63	20.5	113	−.000 003	.000 906	.948	.009 43	20.5	115	−.000 003	.000 887
636 000	400 000	.948	.010 9	23.0	111	−.000 003	.000 918	.948	.010 7	23.0	114	−.000 003	.000 896	.948	.010 5	23.0	116	−.000 003	.000 879
556 500	350 000	.948	.012 3	25.9	111	−.000 004	.000 915	.948	.012 0	25.9	114	−.000 004	.000 893	.948	.011 7	25.9	117	−.000 004	.000 874
477 000	300 000	.948	.014 2	30.3	113	−.000 004	.000 904	.948	.013 8	30.3	116	−.000 004	.000 882	.948	.013 5	30.3	118	−.000 004	.000 863
397 500	250 000	.948	.016 7	36.3	115	−.000 005	.000 890	.948	.016 3	36.3	118	−.000 005	.000 868	.948	.016 0	36.3	120	−.000 005	.000 851
336 400	0 000	.948	.019 5	42.9	117	−.000 006	.000 877	.948	.019 0	42.9	120	−.000 006	.000 857	.948	.018 7	42.9	122	−.000 005	.000 839
266 800	000	.948	.023 9	54.0	120	−.000 007	.000 855	.948	.023 4	54.0	123	−.000 007	.000 835	.948	.022 9	54.0	125	−.000 006	.000 819
0 000	00	.942	.031 1	71.4	135	−.000 009	.000 838	.942	.030 4	71.4	138	−.000 009	.000 819	.942	.029 8	71.4	140	−.000 008	.000 803
000	0	.942	.038 1	89.1	137	−.000 011	.000 872	.942	.037 3	89.1	140	−.000 010	.000 805	.943	.036 6	89.1	142	−.000 010	.000 789
00	1	.942	.046 4	111.	139	−.000 013	.000 808	.943	.045 4	111.	142	−.000 012	.000 791	.943	.044 6	111.	144	−.000 012	.000 777
0	2	.942	.056 8	138.	142	−.000 015	.000 794	.943	.055 5	138.	145	−.000 015	.000 777	.943	.054 5	138.	147	−.000 014	.000 763

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.948	.005 21	11.0	111	−.000 002	.000 918	.948	.005 12	11.0	113	−.000 002	.000 902	.948	.005 04	11.0	115	−.000 002	.000 890
1 272 000	800 000	.948	.005 49	11.6	112	−.000 002	.000 913	.948	.005 41	11.6	114	−.000 002	.000 899	.948	.005 32	11.6	115	−.000 002	.000 885
1 192 500	750 000	.948	.005 82	12.4	112	−.000 002	.000 909	.948	.005 72	12.4	114	−.000 002	.000 893	.948	.005 64	12.4	116	−.000 002	.000 880
1 113 000	700 000	.948	.006 19	13.2	113	−.000 002	.000 904	.948	.006 09	13.2	115	−.000 002	.000 888	.948	.006 00	13.2	117	−.000 002	.000 876
1 033 500	650 000	.948	.006 62	14.2	114	−.000 002	.000 898	.948	.006 50	14.2	115	−.000 002	.000 882	.948	.006 41	14.2	117	−.000 002	.000 869
954 000	600 000	.948	.007 11	15.4	114	−.000 002	.000 891	.948	.006 99	15.4	116	−.000 002	.000 877	.948	.006 89	15.4	118	−.000 002	.000 865
874 500	550 000	.948	.007 71	16.8	115	−.000 002	.000 885	.948	.007 59	16.8	117	−.000 002	.000 871	.948	.007 48	16.8	119	−.000 002	.000 858
795 000	500 000	.948	.008 36	18.4	116	−.000 003	.000 879	.948	.008 21	18.4	118	−.000 002	.000 863	.948	.008 09	18.4	120	−.000 002	.000 851
715 500	450 000	.948	.009 26	20.5	117	−.000 003	.000 871	.948	.009 11	20.5	119	−.000 003	.000 857	.948	.008 98	20.5	121	−.000 003	.000 844
636 000	400 000	.948	.010 3	23.0	118	−.000 003	.000 863	.948	.010 1	23.0	120	−.000 003	.000 849	.948	.009 96	23.0	122	−.000 003	.000 836
556 500	350 000	.948	.011 5	25.9	119	−.000 003	.000 858	.948	.011 4	25.9	121	−.000 003	.000 846	.948	.011 2	25.9	122	−.000 003	.000 833
477 000	300 000	.948	.013 3	30.3	120	−.000 004	.000 849	.948	.013 1	30.3	122	−.000 004	.000 835	.948	.012 9	30.3	124	−.000 004	.000 824
397 500	250 000	.948	.015 7	36.3	122	−.000 004	.000 836	.948	.015 5	36.3	124	−.000 004	.000 824	.948	.015 3	36.3	126	−.000 004	.000 811
336 400	0 000	.948	.018 4	42.9	124	−.000 005	.000 825	.948	.018 1	42.9	126	−.000 005	.000 813	.948	.017 8	42.9	128	−.000 005	.000 802
266 800	000	.948	.022 5	54.0	127	−.000 006	.000 805	.948	.022 2	54.0	129	−.000 006	.000 792	.948	.021 9	54.0	131	−.000 006	.000 783
0 000	00	.942	.029 3	71.4	142	−.000 008	.000 789	.942	.028 9	71.4	144	−.000 008	.000 778	.943	.028 5	71.4	146	−.000 007	.000 767
000	0	.943	.036 0	89.1	144	−.000 010	.000 777	.943	.035 5	89.1	146	−.000 009	.000 766	.943	.035 0	89.1	148	−.000 009	.000 755
00	1	.943	.043 9	111.	146	−.000 011	.000 764	.943	.043 3	111.	148	−.000 011	.000 754	.943	.042 7	111.	150	−.000 011	.000 744
0	2	.943	.053 6	138.	149	−.000 014	.000 751	.943	.052 9	138.	151	−.000 013	.000 741	.943	.052 3	138.	152	−.000 013	.000 732

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE LXIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

170 MILES—273.59 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B. & S.)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.939	.008 58	15.2	110	-.000 003	.001 080	.939	.008 18	15.2	115	-.000 003	.001 030	.939	.007 89	15.2	119	-.000 003	.000 993
600 000	.939	.009 16	16.4	111	-.000 003	.001 070	.939	.008 75	16.4	116	-.000 003	.001 022	.939	.008 43	16.4	120	-.000 003	.000 985
550 000	.939	.009 87	17.8	112	-.000 004	.001 062	.939	.009 42	17.8	117	-.000 003	.001 013	.939	.009 09	17.8	121	-.000 003	.000 978
500 000	.939	.0107	19.5	113	-.000 004	.001 052	.939	.0102	19.5	118	-.000 004	.001 005	.939	.009 88	19.5	122	-.000 003	.000 970
450 000	.939	.0117	21.6	114	-.000 004	.001 042	.939	.0112	21.6	119	-.000 004	.000 995	.939	.0108	21.6	123	-.000 004	.000 962
400 000	.939	.0130	24.2	116	-.000 005	.001 030	.939	.0124	24.2	121	-.000 004	.000 985	.939	.0120	24.2	125	-.000 004	.000 952
350 000	.939	.0146	27.5	117	-.000 005	.001 018	.939	.0140	27.5	122	-.000 005	.000 973	.939	.0135	27.5	126	-.000 004	.000 940
300 000	.939	.0168	32.0	119	-.000 006	.001 003	.939	.0160	32.0	124	-.000 005	.000 960	.939	.0155	32.0	128	-.000 005	.000 929
250 000	.939	.0198	38.4	121	-.000 007	.000 987	.939	.0189	38.4	126	-.000 006	.000 945	.939	.0183	38.4	130	-.000 006	.000 915
0 000	.938	.0229	45.2	124	-.000 008	.000 972	.938	.0220	45.2	128	-.000 007	.000 930	.938	.0213	45.2	133	-.000 007	.000 900
000	.938	.0283	57.0	126	-.000 009	.000 952	.938	.0272	57.0	131	-.000 009	.000 914	.938	.0263	57.0	135	-.000 008	.000 884
00	.938	.0350	71.8	129	-.000 011	.000 934	.938	.0336	71.8	134	-.000 010	.000 897	.938	.0325	71.8	138	-.000 010	.000 869
0	.938	.0433	90.4	131	-.000 014	.000 917	.938	.0416	90.4	136	-.000 013	.000 880	.938	.0403	90.4	141	-.000 012	.000 854
1	.938	.0534	114.	135	-.000 017	.000 899	.938	.0514	114.	139	-.000 015	.000 864	.938	.0499	114.	144	-.000 014	.000 839
2	.938	.0661	144.	138	-.000 020	.000 882	.938	.0636	144.	143	-.000 019	.000 849	.938	.0618	144.	147	-.000 017	.000 824

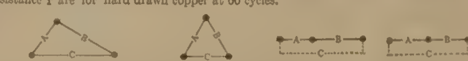
	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.939	.007 66	15.2	123	-.000 003	.000 963	.939	.007 48	15.2	126	-.000 002	.000 942	.939	.007 32	15.2	128	-.000 002	.000 922
600 000	.939	.008 19	16.4	124	-.000 003	.000 957	.939	.008 01	16.4	126	-.000 003	.000 935	.939	.007 84	16.4	129	-.000 002	.000 915
550 000	.939	.008 83	17.8	125	-.000 003	.000 950	.939	.008 63	17.8	128	-.000 003	.000 929	.939	.008 44	17.8	130	-.000 003	.000 909
500 000	.939	.009 60	19.5	126	-.000 003	.000 943	.939	.009 37	19.5	128	-.000 003	.000 920	.939	.009 18	19.5	131	-.000 003	.000 902
450 000	.939	.0105	21.6	127	-.000 003	.000 935	.939	.0103	21.6	130	-.000 003	.000 914	.939	.0101	21.6	132	-.000 003	.000 895
400 000	.939	.0117	24.2	128	-.000 004	.000 925	.939	.0114	24.2	131	-.000 004	.000 904	.939	.0112	24.2	134	-.000 003	.000 885
350 000	.939	.0132	27.5	130	-.000 004	.000 915	.939	.0128	27.5	132	-.000 004	.000 894	.939	.0126	27.5	135	-.000 004	.000 877
300 000	.939	.0151	32.0	131	-.000 005	.000 904	.939	.0148	32.0	134	-.000 004	.000 884	.939	.0145	32.0	136	-.000 004	.000 865
250 000	.939	.0178	38.4	133	-.000 005	.000 890	.939	.0174	38.4	136	-.000 005	.000 870	.939	.0171	38.4	139	-.000 005	.000 854
0 000	.939	.0207	45.2	136	-.000 006	.000 877	.939	.0203	45.2	139	-.000 006	.000 859	.939	.0199	45.2	141	-.000 006	.000 842
000	.938	.0256	57.0	138	-.000 008	.000 862	.939	.0251	57.0	141	-.000 007	.000 844	.939	.0246	57.0	144	-.000 007	.000 827
00	.938	.0317	71.8	141	-.000 009	.000 847	.939	.0310	71.8	144	-.000 009	.000 829	.939	.0305	71.8	146	-.000 009	.000 814
0	.938	.0393	90.4	144	-.000 011	.000 832	.938	.0385	90.4	147	-.000 011	.000 815	.939	.0378	90.4	149	-.000 010	.000 800
1	.938	.0487	114.	147	-.000 014	.000 819	.938	.0476	114.	150	-.000 013	.000 800	.938	.0468	114.	152	-.000 013	.000 787
2	.938	.0603	144.	150	-.000 017	.000 804	.938	.0591	144.	153	-.000 016	.000 789	.938	.0580	144.	156	-.000 015	.000 774

	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.939	.007 19	15.2	130	-.000 002	.000 905	.939	.007 07	15.2	132	-.000 002	.000 890	.939	.006 98	15.2	134	-.000 002	.000 879
600 000	.939	.007 69	16.4	131	-.000 002	.000 899	.939	.007 58	16.4	133	-.000 002	.000 885	.939	.007 47	16.4	135	-.000 002	.000 872
550 000	.939	.008 30	17.8	132	-.000 003	.000 894	.939	.008 17	17.8	134	-.000 002	.000 879	.939	.008 06	17.8	136	-.000 002	.000 867
500 000	.939	.009 03	19.5	133	-.000 003	.000 887	.939	.008 87	19.5	135	-.000 003	.000 872	.939	.008 76	19.5	137	-.000 003	.000 860
450 000	.939	.009 89	21.6	134	-.000 003	.000 879	.939	.009 74	21.6	136	-.000 003	.000 865	.939	.009 61	21.6	138	-.000 003	.000 854
400 000	.939	.0110	24.2	136	-.000 003	.000 870	.939	.0108	24.2	138	-.000 003	.000 857	.939	.0107	24.2	140	-.000 003	.000 845
350 000	.939	.0124	27.5	137	-.000 004	.000 862	.939	.0122	27.5	139	-.000 004	.000 849	.939	.0120	27.5	141	-.000 003	.000 837
300 000	.939	.0142	32.0	139	-.000 004	.000 852	.939	.0140	32.0	141	-.000 004	.000 839	.939	.0138	32.0	143	-.000 004	.000 827
250 000	.939	.0168	38.4	141	-.000 005	.000 840	.939	.0166	38.4	143	-.000 005	.000 827	.939	.0164	38.4	144	-.000 005	.000 817
0 000	.939	.0196	45.2	144	-.000 006	.000 829	.939	.0192	45.2	146	-.000 005	.000 815	.939	.0190	45.2	147	-.000 005	.000 805
000	.939	.0242	57.0	146	-.000 007	.000 814	.939	.0238	57.0	148	-.000 007	.000 802	.939	.0235	57.0	150	-.000 006	.000 792
00	.939	.0300	71.8	149	-.000 008	.000 800	.939	.0295	71.8	151	-.000 008	.000 789	.939	.0292	71.8	152	-.000 008	.000 779
0	.939	.0371	90.4	151	-.000 010	.000 787	.939	.0367	90.4	153	-.000 010	.000 777	.939	.0362	90.4	155	-.000 010	.000 767
1	.939	.0461	114.	154	-.000 012	.000 775	.939	.0454	114.	156	-.000 012	.000 764	.939	.0449	114.	158	-.000 012	.000 755
2	.938	.0572	144.	158	-.000 015	.000 762	.938	.0564	144.	160	-.000 015	.000 752	.938	.0558	144.	162	-.000 014	.000 744

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \cdots\right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \cdots\right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \cdots\right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

170 MILES—273.59 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.941	.00710	11.6	97.7	-.000003	.001178	.941	.00674	11.6	103	-.000003	.001118	.941	.00648	11.6	107	-.000002	.001075
1 272 000	800 000	.941	.00748	12.3	98.3	-.000003	.001170	.941	.00710	12.3	103	-.000003	.001111	.941	.00684	12.3	107	-.000003	.001070
1 192 500	750 000	.941	.00792	13.1	98.8	-.000003	.001163	.941	.00752	13.1	104	-.000003	.001105	.941	.00724	13.1	108	-.000003	.001063
1 113 000	700 000	.941	.00841	14.0	99.5	-.000003	.001155	.941	.00800	14.0	105	-.000003	.001098	.941	.00769	14.0	109	-.000003	.001056
1 033 500	650 000	.941	.00897	15.1	100.	-.000004	.001145	.941	.00854	15.1	105	-.000003	.001090	.941	.00821	15.1	109	-.000003	.001048
954 000	600 000	.941	.00963	16.3	101	-.000004	.001136	.941	.00916	16.3	106	-.000003	.001081	.941	.00882	16.3	110	-.000003	.001041
874 500	550 000	.941	.0104	17.8	102.	-.000004	.001126	.941	.00993	17.8	107	-.000004	.001071	.941	.00955	17.8	111	-.000003	.001031
795 000	500 000	.941	.0113	19.4	103.	-.000004	.001115	.941	.0108	19.4	108	-.000004	.001063	.941	.0104	19.4	112	-.000004	.001023
715 500	450 000	.941	.0125	21.7	104.	-.000005	.001103	.941	.0119	21.7	109	-.000004	.001051	.941	.0115	21.7	113	-.000004	.001015
636 000	400 000	.941	.0138	24.3	105.	-.000005	.001091	.941	.0132	24.3	110	-.000005	.001040	.941	.0127	24.3	114	-.000004	.001003
556 500	350 000	.941	.0155	27.4	106.	-.000006	.001086	.941	.0148	27.4	111	-.000005	.001036	.941	.0142	27.4	115	-.000005	.000998
477 000	300 000	.941	.0178	32.0	107.	-.000007	.001070	.941	.0170	32.0	112	-.000006	.001021	.941	.0164	32.0	117	-.000006	.000985
397 500	250 000	.941	.0210	38.4	109.	-.000008	.001051	.941	.0201	38.4	114	-.000007	.001005	.941	.0194	38.4	119	-.000006	.000970
336 400	0000	.941	.0245	45.4	111.	-.000009	.001036	.941	.0234	45.4	116	-.000008	.000990	.941	.0226	45.4	120	-.000007	.000956
266 800	000	.941	.0299	57.2	115.	-.000010	.001006	.941	.0287	57.2	120	-.000009	.000963	.941	.0277	57.2	124	-.000009	.000930
0000	00	.934	.0388	75.5	131.	-.000013	.000985	.934	.0372	75.5	136	-.000012	.000943	.934	.0359	75.5	140	-.000011	.000911
000	0	.934	.0475	94.2	133.	-.000016	.000965	.934	.0455	94.2	138	-.000014	.000925	.935	.0441	94.2	142	-.000014	.000895
00	1	.934	.0577	117.	135.	-.000019	.000946	.935	.0554	117.	141	-.000017	.000908	.935	.0536	117.	144	-.000016	.000878
0	2	.934	.0705	145.	139.	-.000022	.000928	.935	.0676	145.	143	-.000021	.000890	.935	.0655	145.	147	-.000019	.000863

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.941	.00627	11.6	110	-.000002	.001041	.941	.00611	11.6	113	-.000002	.001015	.941	.00598	11.6	116	-.000002	.000993
1 272 000	800 000	.941	.00662	12.3	111	-.000002	.001036	.941	.00645	12.3	114	-.000002	.001010	.941	.00631	12.3	116	-.000002	.000988
1 192 500	750 000	.941	.00701	13.1	111	-.000002	.001030	.941	.00683	13.1	114	-.000002	.001003	.941	.00668	13.1	117	-.000002	.000981
1 113 000	700 000	.941	.00746	14.0	112	-.000003	.001025	.941	.00727	14.0	115	-.000002	.000998	.941	.00711	14.0	118	-.000002	.000976
1 033 500	650 000	.941	.00796	15.1	113	-.000003	.001016	.941	.00777	15.1	116	-.000003	.000991	.941	.00760	15.1	118	-.000003	.000970
954 000	600 000	.941	.00856	16.3	114	-.000003	.001010	.941	.00834	16.3	117	-.000003	.000985	.941	.00816	16.3	119	-.000003	.000963
874 500	550 000	.941	.00928	17.8	114	-.000003	.001001	.941	.00904	17.8	117	-.000003	.000976	.941	.00886	17.8	120	-.000003	.000956
795 000	500 000	.941	.0100	19.4	115	-.000003	.000993	.941	.00979	19.4	118	-.000003	.000968	.941	.00959	19.4	121	-.000003	.000948
715 500	450 000	.941	.0111	21.7	116	-.000004	.000983	.941	.0109	21.7	119	-.000004	.000960	.941	.0106	21.7	122	-.000003	.000940
636 000	400 000	.941	.0123	24.3	118	-.000004	.000973	.941	.0120	24.3	121	-.000004	.000950	.941	.0118	24.3	123	-.000004	.000931
556 500	350 000	.941	.0139	27.4	118	-.000005	.000970	.941	.0135	27.4	121	-.000004	.000946	.941	.0132	27.4	124	-.000004	.000926
477 000	300 000	.941	.0160	32.0	120	-.000005	.000958	.941	.0156	32.0	123	-.000005	.000935	.941	.0152	32.0	125	-.000005	.000915
397 500	250 000	.941	.0188	38.4	122	-.000006	.000943	.941	.0184	38.4	125	-.000006	.000920	.941	.0180	38.4	127	-.000006	.000901
336 400	0000	.941	.0220	45.4	124	-.000007	.000930	.941	.0215	45.4	127	-.000007	.000908	.941	.0210	45.4	129	-.000006	.000890
266 800	000	.941	.0270	57.2	127	-.000008	.000906	.941	.0263	57.2	130	-.000008	.000885	.941	.0258	57.2	132	-.000008	.000868
0000	00	.935	.0350	75.5	143	-.000011	.000888	.935	.0342	75.5	146	-.000010	.000868	.935	.0336	75.5	149	-.000010	.000852
000	0	.935	.0429	94.2	145	-.000013	.000871	.935	.0420	94.2	148	-.000012	.000853	.935	.0412	94.2	151	-.000012	.000837
00	1	.935	.0523	117.	148	-.000015	.000856	.935	.0512	117.	151	-.000015	.000838	.935	.0503	117.	153	-.000014	.000823
0	2	.935	.0639	145.	151	-.000018	.000842	.935	.0625	145.	154	-.000018	.000824	.936	.0614	145.	156	-.000017	.000809

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.941	.00586	11.6	118	-.000002	.000973	.941	.00576	11.6	120	-.000002	.000956	.941	.00568	11.6	122	-.000002	.000943
1 272 000	800 000	.941	.00619	12.3	119	-.000002	.000968	.941	.00609	12.3	121	-.000002	.000953	.941	.00600	12.3	122	-.000002	.000938
1 192 500	750 000	.941	.00656	13.1	119	-.000002	.000963	.941	.00644	13.1	121	-.000002	.000946	.941	.00635	13.1	123	-.000002	.000933
1 113 000	700 000	.941	.00698	14.0	120	-.000002	.000958	.941	.00686	14.0	122	-.000002	.000941	.941	.00676	14.0	124	-.000002	.000928
1 033 500	650 000	.941	.00746	15.1	120	-.000002	.000951	.941	.00732	15.1	122	-.000002	.000935	.941	.00722	15.1	124	-.000002	.000921
954 000	600 000	.941	.00801	16.3	121	-.000003	.000945	.941	.00788	16.3	123	-.000003	.000930	.941	.00777	16.3	125	-.000002	.000916
874 500	550 000	.941	.00869	17.8	122	-.000003	.000938	.941	.00855	17.8	124	-.000003	.000923	.941	.00843	17.8	126	-.000003	.000910
795 000	500 000	.941	.00942	19.4	123	-.000003	.000931	.941	.00925	19.4	125	-.000003	.000915	.941	.00912	19.4	127	-.000003	.000901
715 500	450 000	.941	.0104	21.7	124	-.000003	.000923	.941	.0103	21.7	126	-.000003	.000908	.941	.0101	21.7	128	-.000003	.000895
636 000	400 000	.941	.0116	24.3	125	-.000004	.000915	.941	.0114	24.3	127	-.000004	.000900	.941	.0112	24.3	129	-.000003	.000886
556 500	350 000	.941	.0130	27.4	126	-.000004	.000910	.941	.0128	27.4	128	-.000004	.000896	.941	.0126	27.4	130	-.000004	.000883
477 000	300 000	.941	.0150	32.0	128	-.000005	.000900	.941	.0147	32.0	130	-.000004	.000885	.941	.0145	32.0	131	-.000004	.000873
397 500	250 000	.941	.0177	38.4	130	-.000005	.000886	.941	.0174	38.4	132	-.000005	.000873	.941	.0172	38.4	133	-.000005	.000860
336 400	0000	.941	.0207	45.4	131	-.000006	.000875	.941	.0204	45.4	133	-.000006	.000861	.941	.0201	45.4	135	-.000006	.000850
266 800	000	.941	.0254	57.2	135	-.000007	.000853	.941	.0250	57.2	137	-.000007	.000840	.941	.0247	57.2	139	-.000007	.000830
0000	00	.935	.0330	75.5	151	-.000009	.000837	.935	.0325	75.5	153	-.000009	.000825	.935	.0321	75.5	155	-.000009	.000813
000	0	.935	.0405	94.2	153	-.000011	.000823	.935	.0400	94.2	155	-.000011	.000812	.936	.0394	94.2	157	-.000011	.000800
00	1	.935	.0495	117.	155	-.000014	.000810	.935	.0487	117.	157	-.000013	.000799	.936	.0481	117.	159	-.000013	.000789
0	2	.936	.0604	145.	158	-.000016	.000795	.936	.0596	145.	160	-.000016	.000785	.936	.0588	145.	162	-.000016	.000775

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ mmhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXXI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

180 MILES—289.68 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.931	.009 60	16.1	117	-.000 004	.001 142	.931	.009 15	16.1	122	-.000 003	.001 089	.931	.008 83	16.1	126	-.000 003	.001 050
600 000	.931	.0102	17.3	118	-.000 004	.001 131	.931	.009 79	17.3	123	-.000 004	.001 080	.931	.009 44	17.3	127	-.000 003	.001 041
550 000	.931	.0110	18.8	118	-.000 004	.001 122	.931	.0105	18.8	124	-.000 004	.001 071	.931	.0102	18.8	128	-.000 004	.001 034
500 000	.931	.0120	20.6	120	-.000 005	.001 112	.931	.0114	20.6	125	-.000 004	.001 062	.931	.0110	20.6	129	-.000 004	.001 025
450 000	.931	.0131	22.7	121	-.000 005	.001 101	.931	.0125	22.7	126	-.000 005	.001 052	.931	.0121	22.7	130	-.000 004	.001 017
400 000	.931	.0145	25.5	122	-.000 005	.001 089	.931	.0139	25.5	128	-.000 005	.001 041	.931	.0134	25.5	132	-.000 005	.001 006
350 000	.931	.0164	29.0	124	-.000 006	.001 077	.931	.0157	29.0	129	-.000 006	.001 029	.931	.0151	29.0	133	-.000 005	.000 994
300 000	.931	.0188	33.8	125	-.000 007	.001 061	.931	.0180	33.8	131	-.000 006	.001 015	.931	.0174	33.8	135	-.000 006	.000 982
250 000	.931	.0221	40.4	127	-.000 008	.001 043	.931	.0212	40.4	133	-.000 007	.000 999	.931	.0205	40.4	137	-.000 007	.000 967
0 000	.931	.0257	47.7	131	-.000 009	.001 027	.931	.0246	47.7	136	-.000 008	.000 983	.931	.0238	47.7	140	-.000 008	.000 952
000	.931	.0316	60.0	133	-.000 011	.001 006	.931	.0304	60.0	139	-.000 010	.000 966	.931	.0294	60.0	143	-.000 009	.000 934
00	.931	.0391	75.6	136	-.000 013	.000 987	.931	.0376	75.6	141	-.000 012	.000 948	.931	.0364	75.6	146	-.000 011	.000 918
0	.931	.0484	95.3	139	-.000 016	.000 969	.931	.0465	95.3	144	-.000 015	.000 931	.931	.0451	95.3	149	-.000 014	.000 902
1	.931	.0598	120.	143	-.000 020	.000 950	.931	.0575	120.	148	-.000 018	.000 913	.931	.0558	120.	152	-.000 017	.000 887
2	.930	.0740	152.	146	-.000 024	.000 932	.930	.0712	152.	152	-.000 022	.000 897	.931	.0691	152.	156	-.000 021	.000 871

	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.932	.008 56	16.1	130	-.000 003	.001 018	.932	.008 37	16.1	133	-.000 003	.000 996	.932	.008 19	16.1	135	-.000 003	.000 974
600 000	.932	.009 17	17.3	131	-.000 003	.001 011	.932	.008 96	17.3	134	-.000 003	.000 989	.932	.008 77	17.3	136	-.000 003	.000 967
550 000	.932	.009 88	18.8	132	-.000 003	.001 004	.932	.009 65	18.8	135	-.000 003	.000 982	.932	.009 45	18.8	137	-.000 003	.000 960
500 000	.932	.0107	20.6	133	-.000 004	.000 997	.932	.0105	20.6	136	-.000 004	.000 973	.932	.0103	20.6	138	-.000 003	.000 953
450 000	.932	.0118	22.7	134	-.000 004	.000 989	.932	.0115	22.7	137	-.000 004	.000 966	.932	.0113	22.7	140	-.000 004	.000 946
400 000	.932	.0131	25.5	135	-.000 004	.000 978	.932	.0128	25.5	139	-.000 004	.000 955	.932	.0125	25.5	141	-.000 004	.000 936
350 000	.932	.0147	29.0	137	-.000 005	.000 967	.932	.0144	29.0	140	-.000 005	.000 945	.932	.0141	29.0	143	-.000 004	.000 927
300 000	.932	.0169	33.8	139	-.000 006	.000 955	.932	.0165	33.8	142	-.000 005	.000 934	.932	.0162	33.8	144	-.000 005	.000 915
250 000	.932	.0199	40.4	141	-.000 006	.000 941	.932	.0195	40.4	144	-.000 006	.000 920	.932	.0191	40.4	146	-.000 006	.000 902
0 000	.931	.0232	47.7	144	-.000 007	.000 927	.931	.0227	47.7	147	-.000 007	.000 908	.931	.0222	47.7	149	-.000 007	.000 890
000	.931	.0287	60.0	146	-.000 009	.000 911	.931	.0281	60.0	149	-.000 009	.000 892	.931	.0275	60.0	152	-.000 008	.000 874
00	.931	.0355	75.6	149	-.000 011	.000 895	.931	.0347	75.6	152	-.000 010	.000 876	.931	.0341	75.6	155	-.000 010	.000 860
0	.931	.0439	95.3	152	-.000 013	.000 880	.931	.0430	95.3	155	-.000 013	.000 862	.931	.0423	95.3	158	-.000 012	.000 846
1	.931	.0545	120.	156	-.000 016	.000 865	.931	.0533	120.	158	-.000 016	.000 846	.931	.0524	120.	161	-.000 015	.000 832
2	.931	.0674	152.	159	-.000 020	.000 850	.931	.0662	152.	162	-.000 019	.000 834	.931	.0649	152.	165	-.000 018	.000 818

	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.932	.008 05	16.1	138	-.000 003	.000 957	.932	.007 91	16.1	140	-.000 003	.000 941	.932	.007 81	16.1	142	-.000 002	.000 929
600 000	.932	.008 61	17.3	139	-.000 003	.000 950	.932	.008 48	17.3	141	-.000 003	.000 936	.932	.008 35	17.3	143	-.000 003	.000 922
550 000	.932	.009 29	18.8	140	-.000 003	.000 945	.932	.009 14	18.8	142	-.000 003	.000 929	.932	.009 02	18.8	144	-.000 003	.000 916
500 000	.932	.0101	20.6	141	-.000 003	.000 938	.932	.009 93	20.6	143	-.000 003	.000 922	.932	.009 80	20.6	145	-.000 003	.000 909
450 000	.932	.0111	22.7	142	-.000 004	.000 929	.932	.0109	22.7	144	-.000 003	.000 915	.932	.0108	22.7	146	-.000 003	.000 902
400 000	.932	.0123	25.5	144	-.000 004	.000 920	.932	.0121	25.5	146	-.000 004	.000 906	.932	.0119	25.5	148	-.000 004	.000 894
350 000	.932	.0139	29.0	145	-.000 004	.000 911	.932	.0136	29.0	147	-.000 004	.000 897	.932	.0135	29.0	149	-.000 004	.000 885
300 000	.932	.0159	33.8	147	-.000 005	.000 901	.932	.0157	33.8	149	-.000 005	.000 887	.932	.0155	33.8	151	-.000 005	.000 874
250 000	.932	.0188	40.4	149	-.000 006	.000 888	.932	.0185	40.4	151	-.000 006	.000 874	.932	.0183	40.4	153	-.000 005	.000 864
0 000	.931	.0219	47.7	152	-.000 007	.000 876	.931	.0215	47.7	154	-.000 006	.000 862	.931	.0213	47.7	156	-.000 006	.000 851
000	.931	.0271	60.0	154	-.000 008	.000 860	.931	.0267	60.0	157	-.000 008	.000 848	.931	.0263	60.0	159	-.000 008	.000 837
00	.931	.0335	75.6	157	-.000 010	.000 846	.931	.0330	75.6	159	-.000 009	.000 834	.931	.0326	75.6	161	-.000 009	.000 823
0	.931	.0416	95.3	160	-.000 012	.000 832	.931	.0410	95.3	162	-.000 012	.000 821	.931	.0405	95.3	164	-.000 011	.000 811
1	.931	.0516	120.	163	-.000 015	.000 820	.931	.0508	120.	166	-.000 014	.000 807	.931	.0503	120.	167	-.000 014	.000 799
2	.931	.0639	152.	167	-.000 018	.000 806	.931	.0631	152.	169	-.000 017	.000 795	.931	.0624	152.	171	-.000 017	.000 786

$$A = \cosh\theta = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40{,}320}+\right) \qquad B = Z\,\frac{\sinh\theta}{\theta} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right) \qquad C = Y\,\frac{\sinh\theta}{\theta} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXXII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

180 MILES—289.68 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

Circular Mils or A. W. G. (B. & S.)	Copper Equivalent Circular Mils or A. W. G. Based upon Copper 97% Alumin 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.934	.007 94	12.2	103	-.000 003	.001 244	.934	.007 54	12.2	108	-.000 003	.001 181	.934	.007 24	12.2	113	-.000003	.001 135
1 272 000	800 000	.934	.008 36	12.9	104	-.000004	.001 236	.934	.007 95	12.9	109	-.000003	.001 174	.934	.007 65	12.9	113	-.000 003	.001 130
1 192 500	750 000	.934	.008 86	13.8	104	-.000004	.001 228	.934	.00841	13.8	110	-.000003	.001 167	.934	.00809	13.8	114	-.000003	.001 123
1 113 000	700 000	.934	.00941	14.7	105	-.000004	.001 220	.934	.008 95	14.7	110	-.000004	.001 160	.934	.00861	14.7	115	-.000003	.001 116
1 033 500	650 000	.934	.0100	15.9	106	-.000004	.001 209	.934	.009 55	15.9	111	-.000004	.001 151	.934	.00919	15.9	116	-.000003	.001 107
954 000	600 000	.934	.0108	17.2	107	-.000004	.001 200	.934	.0103	17 2	112	-.000004	.001 142	.934	.00987	17 2	116	-.000004	.001 100
874 500	550 000	.934	.0117	18.8	108	-.000005	.001 190	.934	.0111	18.8	113	-.000004	.001 132	.934	.0107	18.8	117	-.000004	.001 089
795 000	500 000	.934	.0126	20.5	109	-.000005	.001 177	.934	.0120	20.5	114	-.000005	.001 123	.934	.0116	20.5	118	-.000004	.001 081
715 500	450 000	.934	.0140	22.9	110	-.000006	.001 165	.934	.0133	22.9	115	-.000005	.001 111	.934	.0128	22.9	119	-.000005	.001 072
636 000	400 000	.934	.0155	25.6	111	-.000006	.001 153	.934	.0147	25.6	116	-.000006	.001 098	.934	.0142	25.6	121	-.000005	.001 060
556 500	350 000	.934	.0173	28.9	112	-.000007	.001 148	.934	.0166	28.9	.117	-.000006	.001 095	.934	.0159	28.9	121	-.000006	.001 054
477 000	300 000	.934	.0199	33.7	113	-.000008	.001 130	.934	.0190	33.7	119	-.000007	.001 079	.934	.0183	33.7	123	-.000007	.001 040
397 500	250 000	.934	.0235	40.4	116	-.000009	.001 111	.934	.0225	40.4	121	-.000008	.001 061	.934	.0217	40.4	125	-.000008	.001 074
336 400	0 000	.934	.0274	47.8	118	-.000010	.001 095	.934	.0262	47.8	123	-.000009	.001 045	.934	.0253	47.8	127	-.000009	.001 010
266 800	000	.934	.0335	60.2	121	-.000012	.001 063	.934	.0320	60.2	127	-.000011	.001 017	.934	.0309	60.2	131	-.000010	.000 982
0 000	00	.926	.0434	79.4	138	-.000016	.001 040	.926	.0416	79.4	143	-.000014	.000 996	.927	.0402	79.4	148	-.000013	.000 962
000	0	.926	.0531	99.1	141	-.000019	.001 018	.927	.0509	99.1	146	-.000017	.000 976	.927	.0493	99.2	150	-.000016	.000 945
00	1	.926	.0645	123.	143	-.000022	.000 999	.927	.0620	123.	149	-.000020	.000 959	.927	.0599	123.	153	-.000019	.000 927
0	2	.927	.0788	153.	147	-.000027	.000 980	.927	.0755	153.	152	-.000024	.000 940	.927	.0733	153.	156	-.000023	.000 911

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.934	.007 02	12.2	116	-.000003	.001 100	.934	.006 84	12.2	120	-.000003	.001 072	.934	.006 69	12.2	122	-.000 002	.001 049
1 272 000	800 000	.934	.007 41	12.9	117	-.000003	.001 095	.934	.007 22	12.9	120	-.000003	.001 067	.934	.007 06	12.9	123	-.000003	.001 044
1 192 500	750 000	.934	.007 84	13.8	118	-.000003	.001 088	.934	.007 64	13.8	121	-.000003	.001 060	.934	.007 47	13.8	123	-.000003	.001 037
1 113 000	700 000	.934	.008 35	14.7	118	-.000003	.001 082	.934	.008 13	14.7	121	-.000003	.001 054	.934	.007 96	14.7	124	-.000003	.001 031
1 033 500	650 000	.934	.008 91	15.9	119	-.000003	.001 074	.934	.008 69	15.9	122	-.000003	.001 047	.934	.008 50	15.9	125	-.000003	.001 024
954 000	600 000	.934	.009 57	17.2	120	-.000004	.001 067	.934	.009 33	17.2	123	-.000003	.001 040	.934	.009 13	17.2	126	-.000003	.001 017
874 500	550 000	.934	.0104	18.8	121	-.000004	.001 058	.934	.0101	18.8	124	-.000004	.001 031	.934	.009 91	18.8	127	-.000003	.001 010
795 000	500 000	.934	.0112	20.5	122	-.000004	.001 049	.934	.0110	20.5	125	-.000004	.001 023	.934	.0107	20.5	128	-.000004	.001 001
715 500	450 000	.934	.0124	22.9	123	-.000004	.001 038	.934	.0121	22.9	126	-.000004	.001 014	.934	.0119	22.9	129	-.000004	.000 993
636 000	400 000	.934	.0138	25.6	124	-.000 005	.001 028	.934	.0135	25.6	127	-.000 005	.001 003	.934	.0132	25.6	130	-.000004	.000 984
556 500	350 000	.934	.0155	28.9	125	-.000005	.001 024	.934	.0151	28.9	128	-.000005	.001 000	.934	.0148	28.9	131	-.000005	.000 979
477 000	300 000	.934	.0179	33.7	127	-.000006	.001 012	.934	.0174	33.7	130	-.000006	.000 987	.934	.0170	33.7	132	-.000006	.000 966
397 500	250 000	.934	.0211	40.4	129	-.000 007	.000 996	.934	.0205	40.4	132	-.000 007	.000 972	.934	.0201	40.4	134	-.000 007	.000 952
336 400	0 000	.934	.0246	47.8	131	-.000 008	.000 982	.934	.0240	47.8	134	-.000 008	.000 959	.934	.0235	47.8	136	-.000 008	.000 940
266 800	000	.934	.0302	60.2	134	-.000 010	.000 957	.934	.0295	60.2	137	-.000009	.000 935	.934	.0289	60.2	140	-.000 009	.000 917
0 000	00	.927	.0392	79.4	151	-.000013	.000 938	.927	.0383	79.4	154	-.000 012	.000 917	.927	.0376	79.5	157	-.000 012	.000 899
000	0	.927	.0480	99.2	154	-.000015	.000 920	.927	.0470	99.2	157	-.000 015	.000 901	.927	.0460	99.2	159	-.000 014	.000 883
00	1	.927	.0585	123.	156	-.000018	.000 904	.927	.0572	123.	159	-.000 017	.000 885	.928	.0562	123.	162	-.000 017	.000 869
0	2	.927	.0715	153.	160	-.000 022	.000 889	.927	.0699	153.	163	-.000021	.000 870	.928	.0686	153.	165	-.000020	.000 854

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.934	.006 56	12.2	124	-.000 002	.001 028	.934	.006 45	12.2	127	-.000 002	.001 010	.934	.006 36	12.2	129	-.000002	.000 996
1 272 000	800 000	.934	.006 92	12.9	125	-.000 002	.001 023	.934	.006 81	12.9	127	-.000002	.001 007	.934	.006 71	12.9	129	-.000002	.000 991
1 192 500	750 000	.934	.007 33	13.8	126	-.000 003	.001 017	.934	.007 21	13.8	128	-.000002	.001 000	.934	.007 11	13.8	130	-.000002	.000 986
1 113 000	700 000	.934	.007 81	14.7	126	-.000 003	.001 012	.934	.007 67	14.7	129	-.000003	.000 994	.934	.007 56	14.7	130	-.000 003	.000 980
1 033 500	650 000	.934	.008 34	15.9	127	-.000 003	.001 005	.934	.008 19	15.9	129	-.000003	.000 987	.934	.008 08	15.9	131	-.000003	.000 973
954 000	600 000	.934	.008 95	17.2	128	-.000 003	.000 998	.934	.008 81	17.2	130	-.000003	.000 982	.934	.008 69	17.2	132	-.000003	.000 968
874 500	550 000	.934	.009 72	18.8	129	-.000 003	.000 991	.934	.009 57	18.8	131	-.000003	.000 975	.934	.009 43	18.8	133	-.000 003	.000 961
795 000	500 000	.934	.0105	20.5	130	-.000004	.000 984	.934	.0104	20.5	132	-.000003	.000 966	.934	.0102	20.5	134	-.000 003	.000 952
715 500	450 000	.934	.0117	22.9	131	-.000004	.000 975	.934	.0115	22.9	133	-.000004	.000 959	.934	.0113	22.9	135	-.000 004	.000 945
636 000	400 000	.934	.0130	25.6	132	-.000 004	.000 966	.934	.0127	25.6	134	-.000004	.000 950	.934	.0126	25.6	136	-.000004	.000 936
556 500	350 000	.934	.0145	28.9	133	-.000 005	.000 961	.934	.0143	28.9	135	-.000005	.000 947	.934	.0141	28.9	137	-.000005	.000 933
477 000	300 000	.934	.0168	33.7	135	-.000 005	.000 950	.934	.0165	33.7	137	-.000005	.000 935	.934	.0163	33.7	139	-.000005	.000 922
397 500	250 000	.934	.0198	40.4	137	-.000 006	.000 936	.934	.0195	40.4	139	-.000006	.000 922	.934	.0192	40.4	141	-.000 006	.000 908
336 400	0 000	.934	.0231	47.8	139	-.000 007	.000 924	.934	.0228	47.8	141	-.000007	.000 910	.934	.0225	47.8	143	-.000 007	.000 898
266 800	000	.934	.0284	60.2	143	-.000 009	.000 901	.934	.0279	60.2	145	-.000009	.000 887	.934	.0276	60.2	147	-.000 008	.000 877
0 000	00	.927	.0369	79.5	159	-.000 011	.000 883	.927	.0364	79.5	161	-.000011	.000 871	.927	.0359	79.5	163	-.000011	.000 859
000	0	.927	.0453	99.2	162	-.000 014	.000 869	.928	.0447	99.2	164	-.000013	.000 857	.928	.0440	99.2	166	-.000013	.000 845
00	1	.928	.0553	123.	164	-.000 016	.000 855	.928	.0545	123.	167	-.000016	.000 843	.928	.0538	123.	168	-.000015	.000 833
0	2	.928	.0675	153.	167	-.000 020	.000 840	.928	.0666	153.	170	-.000019	.000 829	.928	.0658	153.	171	-.000019	.000 819

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $g + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

190 MILES—305.78 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.923	.0107	16.8	123	−.000 004	.001 201	.924	.010 2	16.8	128	−.000 004	.001 146	.924	.009 81	16.8	133	−.000 004	.001 105
600 000	.923	.011 4	18.2	124	−.000 005	.001 190	.924	.010 9	18.2	129	−.000 004	.001 137	.924	.010 5	18.2	134	−.000 004	.001 096
550 000	.923	.012 3	19.7	125	−.000 005	.001 181	.924	.011 7	19.7	130	−.000 005	.001 127	.924	.011 3	19.7	135	−.000 004	.001 088
500 000	.923	.013 3	21.6	126	−.000 005	.001 170	.924	.012 7	21.6	131	−.000 005	.001 118	.924	.012 3	21.6	136	−.000 005	.001 079
450 000	.923	.014 6	23.9	127	−.000 006	.001 159	.924	.013 9	23.9	133	−.000 005	.001 107	.924	.013 5	23.9	137	−.000 005	.001 070
400 000	.923	.016 2	26.8	129	−.000 006	.001 146	.924	.015 5	26.8	134	−.000 006	.001 096	.924	.014 9	26.8	139	−.000 005	.001 059
350 000	.923	.018 2	30.5	130	−.000 007	.001 133	.924	.017 4	30.5	136	−.000 007	.001 083	.924	.016 8	30.5	140	−.000 006	.001 046
300 000	.923	.020 8	35.4	132	−.000 008	.001 116	.924	.019 9	35.4	138	−.000 007	.001 068	.924	.019 3	35.4	142	−.000 007	.001 033
250 000	.923	.024 6	42.4	134	−.000 009	.001 098	.924	.023 5	42.4	140	−.000 009	.001 051	.924	.022 8	42.4	144	−.000 008	.001 018
0 000	.923	.028 5	50.1	137	−.000 011	.001 081	.923	.027 3	50.1	143	−.000 010	.001 035	.923	.026 4	50.1	148	−.000 009	.001 001
000	.923	.035 2	63.0	140	−.000 013	.001 059	.923	.033 8	63.0	146	−.000 012	.001 016	.923	.032 6	63.0	150	−.000 011	.000 983
00	.923	.043 4	79.4	143	−.000 016	.001 038	.923	.041 7	79.4	149	−.000 014	.000 998	.923	.040 4	79.4	153	−.000 014	.000 966
0	.923	.053 8	100.	147	−.000 019	.001 020	.923	.051 6	100.	152	−.000 017	.000 979	.923	.050 1	100.	157	−.000 016	.000 950
1	.923	.066 4	126.	150	−.000 023	.001 000	.923	.063 9	126.	156	−.000 021	.000 961	.923	.062 0	126.	160	−.000 020	.000 933
2	.922	.082 2	159.	155	−.000 028	.000 981	.922	.079 1	159.	160	−.000 026	.000 944	.923	.076 8	159.	164	−.000 024	.000 916

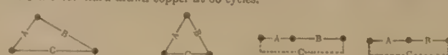
CIRCULAR MILS OR A. W. G (B & S)	13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.924	.009 52	16.8	136	−.000 004	.001 072	.924	.009 30	16.8	140	−.000 003	.001 048	.924	.009 10	16.8	143	−.000 003	.001 025
600 000	.924	.010 2	18.2	138	−.000 004	.001 064	.924	.009 95	18.2	141	−.000 004	.001 040	.924	.009 74	18.2	144	−.000 003	.001 018
550 000	.924	.011 0	19.7	139	−.000 004	.001 057	.924	.010 7	19.7	142	−.000 004	.001 033	.924	.010 5	19.7	145	−.000 004	.001 011
500 000	.924	.011 9	21.6	140	−.000 004	.001 050	.924	.011 6	21.6	143	−.000 004	.001 024	.924	.011 4	21.6	146	−.000 004	.001 003
450 000	.924	.013 1	23.9	141	−.000 005	.001 040	.924	.012 8	23.9	144	−.000 004	.001 016	.924	.012 5	23.9	147	−.000 004	.000 996
400 000	.924	.014 5	26.8	142	−.000 005	.001 029	.924	.014 2	26.8	146	−.000 005	.001 005	.924	.013 9	26.8	149	−.000 005	.000 985
350 000	.924	.016 3	30.5	144	−.000 006	.001 018	.924	.016 0	30.5	147	−.000 005	.000 994	.924	.015 7	30.5	150	−.000 005	.000 975
300 000	.924	.018 8	35.4	146	−.000 007	.001 005	.924	.018 4	35.4	149	−.000 006	.000 983	.924	.018 0	35.4	152	−.000 006	.000 963
250 000	.924	.022 1	42.4	148	−.000 008	.000 990	.924	.021 7	42.4	151	−.000 007	.000 968	.924	.021 2	42.4	154	−.000 007	.000 950
0 000	.923	.025 7	50.1	151	−.000 009	.000 975	.923	.025 2	50.1	154	−.000 008	.000 955	.924	.024 7	50.1	157	−.000 008	.000 937
000	.923	.031 8	63.0	154	−.000 011	.000 959	.923	.031 2	63.0	157	−.000 010	.000 938	.924	.030 6	63.0	160	−.000 010	.000 920
00	.923	.039 4	79.4	157	−.000 013	.000 942	.923	.038 6	79.4	160	−.000 012	.000 922	.923	.037 9	79.4	163	−.000 012	.000 905
0	.923	.048 8	100.	160	−.000 016	.000 926	.923	.047 8	100.	163	−.000 015	.000 907	.923	.046 9	100.	166	−.000 014	.000 890
1	.923	.060 5	126.	164	−.000 019	.000 911	.923	.059 2	126.	167	−.000 018	.000 890	.923	.058 2	126.	170	−.000 018	.000 876
2	.923	.074 9	159.	168	−.000 023	.000 894	.923	.073 5	159.	171	−.000 022	.000 877	.923	.072 1	159.	174	−.000 021	.000 861

CIRCULAR MILS OR A. W. G (B & S)	19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
650 000	.924	.008 94	16.8	145	−.000 003	.001 007	.924	.008 79	16.8	147	−.000 003	.000 990	.924	.008 68	16.8	149	−.000 003	.000 977
600 000	.924	.009 57	18.2	146	−.000 003	.001 000	.924	.009 42	18.2	148	−.000 003	.000 985	.924	.009 28	18.2	150	−.000 003	.000 970
550 000	.924	.010 3	19.7	147	−.000 004	.000 994	.924	.010 2	19.7	149	−.000 003	.000 977	.924	.010 0	19.7	151	−.000 003	.000 964
500 000	.924	.011 2	21.6	148	−.000 004	.000 987	.924	.011 0	21.6	150	−.000 004	.000 970	.924	.010 9	21.6	152	−.000 004	.000 957
450 000	.924	.012 3	23.9	149	−.000 004	.000 977	.924	.012 1	23.9	152	−.000 004	.000 963	.924	.011 9	23.9	154	−.000 004	.000 950
400 000	.924	.013 7	26.8	151	−.000 005	.000 968	.924	.013 4	26.8	153	−.000 004	.000 953	.924	.013 3	26.8	155	−.000 004	.000 940
350 000	.924	.015 4	30.5	153	−.000 005	.000 959	.924	.015 2	30.5	155	−.000 005	.000 944	.924	.015 0	30.5	157	−.000 005	.000 931
300 000	.924	.017 7	35.4	154	−.000 006	.000 948	.924	.017 4	35.4	157	−.000 006	.000 933	.924	.017 2	35.4	159	−.000 005	.000 920
250 000	.924	.020 9	42.4	157	−.000 007	.000 935	.924	.020 6	42.4	159	−.000 007	.000 920	.924	.020 3	42.4	161	−.000 006	.000 909
0 000	.924	.024 3	50.1	160	−.000 008	.000 922	.924	.023 9	50.1	162	−.000 008	.000 907	.924	.023 6	50.1	164	−.000 007	.000 896
000	.924	.030 1	63.0	163	−.000 009	.000 905	.924	.029 6	63.0	165	−.000 009	.000 892	.924	.029 3	63.0	167	−.000 009	.000 881
00	.924	.037 3	79.4	166	−.000 011	.000 890	.924	.036 7	79.4	168	−.000 011	.000 877	.924	.036 3	79.4	170	−.000 011	.000 866
0	.924	.046 2	100.	169	−.000 014	.000 876	.924	.045 6	100.	171	−.000 014	.000 864	.924	.045 0	100.	173	−.000 013	.000 853
1	.923	.057 3	126.	172	−.000 017	.000 863	.923	.056 5	126.	174	−.000 017	.000 850	.923	.055 9	126.	176	−.000 016	.000 840
2	.923	.071 0	159.	176	−.000 021	.000 848	.923	.070 1	159.	178	−.000 020	.000 837	.923	.069 3	159.	180	−.000 020	.000 827

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

190 MILES—305.78 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	7 FEET—2.134 METERS						9 FEET—2.743 METERS						11 FEET—3.353 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.926	.008 82	12.8	109	-.000 004	.001 310	.926	.008 37	12.8	114	-.000 004	.001 243	.926	.008 05	12.8	119	-.000 003	.001 195
1 272 000	800 000	.926	.009 29	13.6	109	-.000004	.001 301	.926	.008 83	13.6	115	-.000 004	.001 236	.926	.008 50	13.6	119	-.000 003	.001 190
1 192 500	750 000	.926	.009 84	14.5	110	-.000004	.001 293	.926	.009 35	14.5	116	-.000004	.001 229	.926	.008 99	14.5	120	-.000 004	.001 182
1 113 000	700 000	.926	.010 5	15.5	111	-.000005	.001 284	.926	.009 94	15.5	116	-.000 004	.001 221	.926	.009 56	15.5	121	-.000 004	.001 175
1 033 500	650 000	.926	.011 2	16.7	112	-.000 005	.001 275	.926	.010 6	16.7	117	-.000 004	.001 212	.926	.010 2	16.7	122	-.000 004	.001 166
954 000	600 000	.926	.012 0	18.0	112	-.000 005	.001 264	.926	.011 4	18.0	118	-.000 005	.001 203	.926	.011 0	18.0	123	-.000 004	.001 158
874 500	550 000	.926	.013 0	19.7	113	-.000006	.001 253	.926	.012 3	19.7	119	-.000005	.001 191	.926	.011 9	19.7	124	-.000 005	.001 147
795 000	500 000	.926	.014 0	21.5	114	-.000006	.001 240	.926	.013 4	21.5	120	-.000005	.001 182	.926	.012 9	21.5	124	-.000005	.001 138
715 500	450 000	.926	.015 5	24.0	116	-.000 007	.001 227	.926	.014 8	24.0	121	-.000006	.001 169	.926	.014 3	24.0	126	-.000006	.001 128
636 000	400 000	.926	.017 2	26.9	117	-.000007	.001 214	.926	.016 4	26.9	123	-.000007	.001 156	.926	.015 8	26.9	127	-.000 006	.001 116
556 500	350 000	.926	.019 3	30.3	118	-.000008	.001 208	.926	.018 4	30.3	123	-.000007	.001 153	.926	.017 7	30.3	128	-.000007	.001 110
477 000	300 000	.926	.022 1	35.4	119	-.000009	.001 190	.926	.021 1	35.4	125	-.000008	.001 136	.926	.020 4	35.4	130	-.000008	.001 095
397 500	250 000	.926	.026 1	42.4	122	-.000011	.001 169	.926	.024 9	42.4	127	-.000010	.001 117	.926	.024 1	42.4	132	-.000 009	.001 078
336 400	0 000	.926	.030 4	50.2	124	-.000012	.001 153	.926	.029 1	50.2	130	-.000011	.001 101	.926	.028 1	50.2	134	-.000010	.001 064
266 800	000	.926	.037 2	63.2	128	-.000014	.001 119	.926	.035 6	63.2	133	-.000013	.001 071	.926	.034 4	63.2	138	-.000012	.001 034
0 000	00	.917	.048 2	83.4	146	-.000018	.001 094	.918	.046 2	83.4	[illegible]	-.000017	.001 048	.918	.044 6	83.4	156	-.000016	.001 013
000	0	.918	.058 9	104.	148	-.000022	.001 072	.918	.056 5	104.	154	-.000020	.001 027	.919	.054 7	104.	158	-.000019	.000 995
00	1	.918	.071 7	129.	151	-.000026	.001 052	.918	.068 8	129.	157	-.000024	.001 010	.919	.066 6	129.	161	-.000 023	.000 976
0	2	.918	.087 5	161.	155	-.000031	.001 032	.919	.083 9	161.	161	-.000029	.000 989	.919	.081 4	161.	165	-.000 027	.000 960

		13 FEET—3.962 METERS						15 FEET—4.572 METERS						17 FEET—5.182 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.926	.007 80	12.8	123	-.000 003	.001 158	.926	.007 60	12.8	126	-.000 003	.001 128	.926	.007 44	12.8	129	-.000 003	.001 104
1 272 000	800 000	.926	.008 23	13.6	123	-.000 003	.001 153	.926	.008 02	13.6	126	-.000 003	.001 123	.926	.007 85	13.6	129	-.000 003	.001 099
1 192 500	750 000	.926	.008 71	14.5	124	-.000 003	.001 145	.926	.008 49	14.5	127	-.000 003	.001 116	.926	.008 30	14.5	130	-.000 003	.001 091
1 113 000	700 000	.926	.009 28	15.5	125	-.000 004	.001 140	.926	.009 03	15.5	128	-.000 003	.001 110	.926	.008 84	15.5	131	-.000 003	.001 086
1 033 500	650 000	.926	.009 90	16.7	125	-.000 004	.001 130	.926	.009 66	16.7	129	-.000 004	.001 103	.926	.009 44	16.7	132	-.000 004	.001 078
954 000	600 000	.926	.010 6	18.0	126	-.000 004	.001 123	.926	.010 4	18.0	130	-.000 004	.001 095	.926	.010 1	18.0	132	-.000 004	.001 071
874 500	550 000	.926	.011 5	19.7	127	-.000 004	.001 114	.927	.011 2	19.7	130	-.000 004	.001 086	.927	.011 0	19.7	133	-.000 004	.001 064
795 000	500 000	.926	.012 5	21.5	128	-.000 005	.001 104	.927	.012 2	21.5	132	-.000 005	.001 077	.927	.011 9	21.5	134	-.000 004	.001 054
715 500	450 000	.927	.013 8	24.0	129	-.000 005	.001 093	.927	.013 5	24.0	133	-.000 005	.001 067	.927	.013 2	24.0	136	-.000 005	.001 045
636 000	400 000	.927	.015 3	26.9	131	-.000 006	.001 082	.927	.015 0	26.9	134	-.000 005	.001 056	.927	.014 7	26.9	137	-.000 005	.001 036
556 500	350 000	.926	.017 2	30.3	131	-.000 006	.001 078	.926	.016 8	30.3	135	-.000 006	.001 053	.927	.016 4	30.3	138	-.000 006	.001 030
477 000	300 000	.926	.019 8	35.4	133	-.000 007	.001 065	.926	.019 4	35.4	136	-.000 007	.001 040	.927	.018 9	35.4	139	-.000 007	.001 017
397 500	250 000	.926	.023 4	42.4	136	-.000 008	.001 049	.926	.022 8	42.4	139	-.000 008	.001 023	.926	.022 4	42.4	142	-.000 008	.001 002
336 400	0 000	.926	.027 3	50.2	138	-.000 010	.001 034	.926	.026 7	50.2	141	-.000 009	.001 010	.926	.026 1	50.2	144	-.000 009	.000 990
266 800	000	.926	.033 5	63.2	142	-.000 012	.001 008	.926	.032 7	63.2	145	-.000 011	.000 984	.926	.032 1	63.2	148	-.000 011	.000 965
0 000	00	.918	.043 5	83.4	159	-.000 015	.000 987	.919	.042 5	83.4	162	-.000 014	.000 965	.919	.041 7	83.4	165	-.000 014	.000 947
000	0	.919	.055 3	104.	162	-.000 018	.000 969	.919	.052 2	104.	165	-.000 017	.000 949	.919	.051 1	104.	168	-.000 016	.000 930
00	1	.919	.064 9	129.	165	-.000 021	.000 952	.919	.063 6	129.	168	-.000 021	.000 932	.919	.062 4	129.	171	-.000 020	.000 915
0	2	.919	.079 4	161.	168	-.000 026	.000 936	.919	.077 7	161.	172	-.000 025	.000 916	.919	.076 3	161.	174	-.000 024	.000 899

		19 FEET—5.791 METERS						21 FEET—6.401 METERS						23 FEET—7.010 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 351 500	850 000	.926	.007 29	12.8	131	-.000 003	.001 082	.926	.007 16	12.8	133	-.000 003	.001 064	.926	.007 06	12.8	135	-.000 003	.001 049
1 272 000	800 000	.926	007 69	13.6	132	-.000 003	.001 077	.926	.007 57	13.6	134	-.000 003	.001 060	.926	.007 45	13.6	136	-.000 003	.001 043
1 192 500	750 000	.926	.008 15	14.5	132	-.000 003	.001 071	.926	.008 01	14.5	135	-.000 003	.001 053	.926	.007 90	14.5	137	-.000 003	.001 038
1 113 000	700 000	.926	.008 67	15.5	133	-.000 003	.001 065	.926	.008 52	15.5	135	-.000 003	.001 047	.926	.008 40	15.5	137	-.000 003	.001 032
1 033 500	650 000	.926	.009 27	16.7	134	-.000 003	.001 058	.926	.009 10	16.7	136	-.000 003	.001 040	.926	.008 97	16.7	138	-.000 003	.001 025
954 000	600 000	.926	.009 95	18.0	135	-.000 004	.001 051	.926	.009 79	18.0	137	-.000 003	.001 034	.926	.009 65	18.0	139	-.000 003	.001 019
874 500	550 000	.927	.010 8	19.7	136	-.000 004	.001 043	.927	.010 6	19.7	138	-.000 004	.001 027	.927	.010 5	19.7	140	-.000 004	.001 012
795 000	500 000	.927	.011 7	21.5	137	-.000 004	.001 036	.927	.011 5	21.5	139	-.000 004	.001 017	.927	.011 3	21.5	141	-.000 004	.001 002
715 500	450 000	.927	.013 0	24.0	138	-.000 005	.001 027	.927	.012 8	24.0	140	-.000 004	.001 010	.927	.012 6	24.0	142	-.000 004	.000 995
636 000	400 000	.927	.014 4	26.9	139	-.000 005	.001 017	.927	.014 2	26.9	142	-.000 005	.001 001	.927	.014 0	26.9	144	-.000 005	.000 986
556 500	350 000	.927	.016 1	30.3	140	-.000 006	.001 012	.927	.015 9	30.3	142	-.000 005	.000 997	.927	.015 7	30.3	144	-.000 005	.000 982
477 000	300 000	.926	.018 6	35.4	142	-.000 006	.001 001	.926	.018 3	35.4	144	-.000 006	.000 984	.926	.018 1	35.4	146	-.000 006	.000 971
397 500	250 000	.926	.022 0	42.4	144	-.000 007	.000 986	.926	.021 7	42.4	146	-.000 007	.000 971	.926	.021 4	42.4	148	-.000 007	.000 956
336 400	0 000	.926	.025 7	50.2	146	-.000 009	.000 973	.926	.025 3	50.2	149	-.000 008	.000 958	.926	.025 0	50.2	150	-.000 008	.000 945
266 800	000	.926	.031 5	63.2	150	-.000 010	.000 949	.926	.031 1	63.2	152	-.000 010	.000 934	.926	.030 7	63.2	154	-.000 010	.000 923
0 000	00	.919	.041 0	83.4	168	-.000 013	.000 930	.919	.040 4	83.4	170	-.000 013	.000 917	.919	.039 8	83.4	172	-.000 012	.000 904
000	0	.919	.050 3	104.	170	-.000 016	.000 915	.919	.049 6	104.	173	-.000 015	.000 902	.920	.048 9	104.	175	-.000 015	.000 889
00	1	.919	.061 4	129.	173	-.000 019	.000 901	.920	.060 6	129.	176	-.000 019	.000 888	.920	.059 8	129.	178	-.000 018	.000 877
0	2	.920	.075 0	161.	177	-.000 023	.000 884	.920	.074 1	161.	179	-.000 022	.000 873	.920	.073 1	161.	181	-.000 022	.000 862

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. — Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXXV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

200 MILES—321.87 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B. & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.915	.007 96	12.0	130	−.000 003	.001 252	.916	.007 66	12.0	134	−.000 003	.001 205	.916	.007 44	12.0	138	−.000 003	.001 170
950 000	.915	.008 27	12.5	130	−.000 004	.001 246	.916	.007 96	12.5	135	−.000 003	.001 199	.916	.007 73	12.5	139	−.000 003	.001 164
900 000	.915	.008 63	13.1	131	−.000 004	.001 240	.916	.008 31	13.1	136	−.000 003	.001 194	.916	.008 06	13.1	139	−.000 003	.001 159
850 000	.915	.009 02	13.8	131	−.000 004	.001 232	.916	.008 69	13.8	136	−.000 004	.001 188	.916	.008 44	13.8	140	−.000 003	.001 153
800 000	.915	.009 48	14.6	132	−.000 004	.001 227	.916	.009 13	14.6	137	−.000 004	.001 182	.916	.008 86	14.6	141	−.000 004	.001 147
750 000	.915	.009 98	15.5	133	−.000 004	.001 219	.916	.009 61	15.5	138	−.000 004	.001 174	.916	.009 34	15.5	142	−.000 004	.001 141
700 000	.915	.010 6	16.5	134	−.000 004	.001 211	.916	.010 2	16.5	138	−.000 004	.001 168	.916	.009 88	16.5	143	−.000 004	.001 133
650 000	.915	.011 2	17.6	135	−.000 005	.001 203	.916	.010 8	17.6	139	−.000 004	.001 161	.916	.010 5	17.6	143	−.000 004	.001 126
600 000	.915	.012 0	19.0	136	−.000 005	.001 194	.916	.011 6	19.0	141	−.000 005	.001 151	.916	.011 2	19.0	145	−.000 004	.001 118
550 000	.915	.012 9	20.6	137	−.000 005	.001 184	.916	.012 5	20.6	142	−.000 005	.001 143	.916	.012 1	20.6	146	−.000 005	.001 110
500 000	.915	.014 0	22.6	138	−.000 006	.001 174	.916	.013 6	22.6	143	−.000 005	.001 133	.916	.013 2	22.6	147	−.000 005	.001 102
450 000	.915	.015 4	25.0	139	−.000 006	.001 163	.916	.014 9	25.0	144	−.000 006	.001 124	.916	.014 5	25.0	148	−.000 005	.001 093
400 000	.915	.017 1	28.0	141	−.000 007	.001 151	.916	.016 5	28.0	146	−.000 006	.001 112	.916	.016 0	28.0	150	−.000 006	.001 081
350 000	.915	.019 2	31.9	143	−.000 008	.001 137	.916	.018 6	31.9	147	−.000 007	.001 098	.916	.018 1	31.9	151	−.000 007	.001 069
300 000	.916	.022 0	37.1	145	−.000 009	.001 122	.916	.021 3	37.1	149	−.000 008	.001 085	.916	.020 8	37.1	153	−.000 008	.001 056
250 000	.916	.026 0	44.4	147	−.000 010	.001 104	.916	.025 2	44.4	152	−.000 009	.001 069	.916	.024 5	44.4	156	−.000 009	.001 040
0 000	.915	.030 2	52.4	150	−.000 011	.001 087	.915	.029 2	52.4	155	−.000 011	.001 052	.915	.028 4	52.4	159	−.000 010	.001 024
000	.915	.037 3	66.0	153	−.000 014	.001 067	.915	.036 1	66.0	158	−.000 013	.001 032	.915	.035 2	66.0	162	−.000 012	.001 007
00	.915	.046 1	83.1	156	−.000 017	.001 048	.915	.044 7	83.1	161	−.000 016	.001 015	.915	.043 5	83.1	165	−.000 015	.000 989

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.916	.007 25	12.0	142	−.000 003	.001 141	.916	.007 09	12.0	145	−.000 003	.001 116	.916	.006 97	12.0	147	−.000 003	.001 096
950 000	.916	.007 54	12.5	142	−.000 003	.001 135	.916	.007 38	12.5	145	−.000 003	.001 112	.916	.007 24	12.5	148	−.000 003	.001 091
900 000	.916	.007 86	13.1	143	−.000 003	.001 129	.916	.007 70	13.1	146	−.000 003	.001 106	.916	.007 56	13.1	148	−.000 003	.001 087
850 000	.916	.008 24	13.8	144	−.000 003	.001 126	.916	.008 05	13.8	146	−.000 003	.001 100	.916	.007 91	13.8	149	−.000 003	.001 081
800 000	.916	.008 65	14.6	144	−.000 003	.001 120	.916	.008 47	14.6	147	−.000 003	.001 096	.916	.008 30	14.6	150	−.000 003	.001 075
750 000	.916	.009 10	15.5	145	−.000 004	.001 112	.916	.008 93	15.5	148	−.000 003	.001 091	.916	.008 76	15.5	151	−.000 003	.001 069
700 000	.916	.009 65	16.5	146	−.000 004	.001 106	.916	.009 44	16.5	149	−.000 004	.001 083	.916	.009 27	16.5	151	−.000 003	.001 063
650 000	.916	.010 3	17.6	147	−.000 004	.001 100	.916	.010 1	17.6	150	−.000 004	.001 077	.916	.009 88	17.6	152	−.000 004	.001 058
600 000	.916	.011 0	19.0	148	−.000 004	.001 093	.916	.010 8	19.0	151	−.000 004	.001 069	.916	.010 6	19.0	153	−.000 004	.001 050
550 000	.916	.011 9	20.6	149	−.000 004	.001 085	.916	.011 6	20.6	152	−.000 004	.001 061	.916	.011 4	20.6	154	−.000 004	.001 044
500 000	.916	.012 9	22.6	150	−.000 005	.001 075	.916	.012 6	22.6	153	−.000 005	.001 054	.916	.012 4	22.6	156	−.000 004	.001 036
450 000	.916	.014 1	25.0	151	−.000 005	.001 067	.916	.013 8	25.0	154	−.000 005	.001 046	.916	.013 6	25.0	157	−.000 005	.001 026
400 000	.916	.015 7	28.0	153	−.000 006	.001 056	.916	.015 3	28.0	156	−.000 006	.001 034	.916	.015 1	28.0	159	−.000 005	.001 017
350 000	.916	.017 6	31.9	155	−.000 006	.001 044	.916	.017 3	31.9	158	−.000 006	.001 024	.916	.017 0	31.9	160	−.000 006	.001 007
300 000	.916	.020 3	37.1	157	−.000 007	.001 032	.916	.019 9	37.1	159	−.000 007	.001 011	.916	.019 6	37.1	162	−.000 007	.000 995
250 000	.915	.023 9	44.4	159	−.000 008	.001 017	.916	.023 5	44.4	162	−.000 008	.000 997	.916	.023 1	44.4	164	−.000 008	.000 982
0 000	.915	.027 8	52.4	162	−.000 010	.001 003	.915	.027 3	52.4	165	−.000 009	.000 984	.915	.026 9	52.4	168	−.000 009	.000 968
000	.915	.034 4	66.0	165	−.000 012	.000 986	.915	.033 7	66.0	168	−.000 011	.000 966	.915	.033 2	66.0	171	−.000 011	.000 951
00	.915	.042 6	83.1	168	−.000 014	.000 968	.915	.041 8	83.1	171	−.000 014	.000 951	.915	.041 2	83.1	174	−.000 013	.000 935

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.916	.006 84	12.0	150	−.000 003	.001 077	.916	.006 74	12.0	152	−.000 002	.001 061	.916	.006 66	12.0	154	−.000 002	.001 048
950 000	.916	.007 12	12.5	150	−.000 003	.001 073	.916	.007 02	12.5	152	−.000 003	.001 058	.916	.006 93	12.5	154	−.000 003	.001 044
900 000	.916	.007 44	13.1	151	−.000 003	.001 069	.916	.007 33	13.1	153	−.000 003	.001 054	.916	.007 22	13.1	155	−.000 003	.001 038
850 000	.916	.007 78	13.8	151	−.000 003	.001 063	.916	.007 67	13.8	154	−.000 003	.001 048	.916	.007 57	13.8	156	−.000 003	.001 034
800 000	.916	.008 17	14.6	152	−.000 003	.001 058	.916	.008 05	14.6	154	−.000 003	.001 042	.916	.007 94	14.6	156	−.000 003	.001 028
750 000	.916	.008 61	15.5	153	−.000 003	.001 052	.916	.008 50	15.5	155	−.000 003	.001 038	.916	.008 39	15.5	157	−.000 003	.001 024
700 000	.916	.009 12	16.5	154	−.000 003	.001 046	.916	.009 00	16.5	156	−.000 003	.001 032	.916	.008 88	16.5	158	−.000 003	.001 019
650 000	.916	.009 71	17.6	155	−.000 004	.001 040	.916	.009 58	17.6	157	−.000 003	.001 026	.916	.009 46	17.6	159	−.000 003	.001 013
600 000	.916	.010 4	19.0	156	−.000 004	.001 034	.916	.010 3	19.0	158	−.000 004	.001 019	.916	.010 1	19.0	160	−.000 004	.001 007
550 000	.916	.011 2	20.6	157	−.000 004	.001 026	.916	.011 1	20.6	159	−.000 004	.001 013	.916	.010 9	20.6	161	−.000 004	.000 999
500 000	.916	.012 2	22.6	158	−.000 004	.001 019	.916	.012 0	22.6	160	−.000 004	.001 005	.916	.011 9	22.6	162	−.000 004	.000 991
450 000	.916	.013 4	25.0	159	−.000 005	.001 011	.916	.013 2	25.0	161	−.000 005	.000 997	.916	.013 0	25.0	163	−.000 004	.000 984
400 000	.916	.014 9	28.0	161	−.000 005	.001 001	.916	.014 6	28.0	163	−.000 005	.000 988	.916	.014 5	28.0	165	−.000 005	.000 976
350 000	.916	.016 7	31.9	163	−.000 006	.000 991	.916	.016 5	31.9	165	−.000 006	.000 978	.916	.016 3	31.9	167	−.000 005	.000 966
300 000	.916	.019 3	37.1	165	−.000 007	.000 980	.916	.019 0	37.1	167	−.000 006	.000 966	.916	.018 8	37.1	169	−.000 006	.000 955
250 000	.916	.022 7	44.4	167	−.000 008	.000 966	.916	.022 5	44.4	169	−.000 007	.000 955	.916	.022 2	44.4	171	−.000 007	.000 943
0 000	.916	.026 4	52.4	170	−.000 009	.000 953	.916	.026 1	52.4	172	−.000 009	.000 941	.916	.025 8	52.4	174	−.000 008	.000 929
000	.916	.032 7	66.0	173	−.000 011	.000 937	.916	.032 3	66.0	175	−.000 010	.000 925	.916	.031 9	66.0	177	−.000 010	.000 914
00	.916	.040 6	83.1	176	−.000 013	.000 921	.916	.040 0	83.1	178	−.000 013	.000 910	.916	.039 6	83.1	180	−.000 012	.000 900

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXXVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

200 MILES—321.87 Km.

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A W G BASED UPON COPPER 97% ALUMIN 61%	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★																																			
		9 FEET—2.743 METERS												11 FEET—3.353 METERS												13 FEET—3.962 METERS											
		A		B		C								A		B		C								A		B		C							
		a_1	ja_2	b_1	jb_2	c_1	jc_2							a_1	ja_2	b_1	jb_2	c_1	jc_2							a_1	ja_2	b_1	jb_2	c_1	jc_2						

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT	9 ft a_1	9 ft ja_2	9 ft b_1	9 ft jb_2	9 ft c_1	9 ft jc_2	11 ft a_1	11 ft ja_2	11 ft b_1	11 ft jb_2	11 ft c_1	11 ft jc_2	13 ft a_1	13 ft ja_2	13 ft b_1	13 ft jb_2	13 ft c_1	13 ft jc_2
1 590 000	1 000 000	.918	.008 05	11.5	118	-.000 004	.001 326	.918	.007 75	11.5	123	-.000 003	.001 276	.918	.007 50	11.5	127	-.000003	.001 235
1 510 500	950 000	.918	.008 41	12.1	119	-.000 004	.001 321	.918	.008 08	12.1	124	-.000004	.001 268	.918	.007 83	12.1	127	-.000003	.001 229
1 431 000	900 000	.918	.008 81	12.7	119	-.000 004	.001 313	.918	.008 47	12.7	124	-.000004	.001 262	.918	.008 21	12.7	128	-.000003	.001 223
1 351 500	850 000	.918	.009 25	13.4	120	-.000 004	.001 305	.918	.008 89	13.4	125	-.000004	.001 255	.918	.008 62	13.4	129	-.000004	.001 216
1 272 000	800 000	.918	.009 76	14.2	121	-.000 004	.001 297	.918	.009 39	14.2	125	-.000004	.001 249	.918	.009 10	14.2	129	-.000004	.001 210
1 192 500	750 000	.918	.010 3	15.2	122	-.000 005	.001 290	.918	.009 94	15.2	126	-.000004	.001 241	.918	.009 63	15.2	130	-.000004	.001 202
1 113 000	700 000	.918	.011 0	16.2	122	-.000 005	.001 282	.918	.010 6	16.2	127	-.000005	.001 233	.918	.010 3	16.2	131	-.000004	.001 196
1 033 500	650 000	.918	.011 7	17.4	123	-.000 005	.001 272	.919	.011 3	17.4	128	-.000005	.001 223	.919	.010 9	17.4	132	-.000004	.001 186
954 000	600 000	.918	.012 6	18.9	124	-.000 006	.001 262	.919	.012 1	18.9	129	-.000005	.001 216	.919	.011 8	18.9	133	-.000005	.001 179
874 500	550 000	.919	.013 6	20.6	125	-.000 006	.001 251	.919	.013 1	20.6	130	-.000005	.001 204	.919	.012 7	20.6	134	-.000005	.001 169
795 000	500 000	.919	.014 8	22.5	126	-.000 006	.001 241	.919	.014 2	22.5	131	-.000006	.001 194	.919	.013 8	22.5	135	-.000006	.001 159
715 500	450 000	.919	.016 3	25.2	127	-.000 007	.001 227	.919	.015 8	25.2	132	-.000006	.001 185	.919	.015 3	25.2	136	-.000006	.001 148
636 000	400 000	.919	.018 1	28.2	129	-.000 008	.001 214	.919	.017 5	28.2	133	-.000007	.001 171	.919	.016 9	28.2	137	-.000007	.001 136
556 500	350 000	.918	.020 3	31.8	129	-.000 009	.001 210	.919	.019 6	31.8	134	-.000008	.001 165	.919	.019 0	31.8	138	-.000007	.001 132
477 000	300 000	.918	.023 4	37.1	131	-.000 010	.001 192	.919	.022 5	37.1	136	-.000009	.001 149	.919	.021 9	37.1	140	-.000008	.001 118
397 500	250 000	.918	.027 6	44.4	134	-.000 011	.001 173	.918	.026 6	44.4	139	-.000010	.001 132	.918	.025 9	44.4	142	-.000010	.001 101
336 400	0000	.918	.032 1	52.6	136	-.000 013	.001 155	.918	.031 0	52.6	141	-.000012	.001 116	.918	.030 2	52.6	145	-.000011	.001 085
266 800	000	.918	.039 4	66.2	140	-.000 015	.001 124	.918	.038 0	66.2	145	-.000014	.001 085	.918	.037 0	66.2	149	-.000014	.001 058
0000	00	.909	.051 0	87.2	159	-.000 020	.001 100	.909	.049 3	87.2	164	-.000018	.001 063	.910	.048 1	87.2	167	-.000017	.001 036

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT	15 FEET—4.572 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	17 FEET—5.182 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	19 FEET—5.791 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.918	.007 30	11.5	130	-.000 003	.001 202	.918	.007 13	11.5	133	-.000 003	.001 175	.918	.007 00	11.5	136	-.000 003	.001 153
1 510 500	950 000	.918	.007 62	12.1	131	-.000 003	.001 196	.918	.007 46	12.1	134	-.000 003	.001 171	.918	.007 31	12.1	136	-.000 003	.001 148
1 431 000	900 000	.918	.007 99	12.7	132	-.000 003	.001 190	.918	.007 82	12.7	134	-.000 003	.001 165	.919	.007 66	12.7	137	-.000 003	.001 142
1 351 500	850 000	.918	.008 40	13.4	132	-.000 003	.001 185	.918	.008 22	13.4	135	-.000 003	.001 159	.919	.008 05	13.4	138	-.000 003	.001 136
1 272 000	800 000	.918	.008 86	14.2	133	-.000 004	.001 179	.918	.008 67	14.2	136	-.000 003	.001 153	.919	.008 50	14.2	138	-.000 003	.001 130
1 192 500	750 000	.918	.009 38	15.2	134	-.000 004	.001 171	.918	.009 18	15.2	136	-.000 004	.001 146	.919	.009 01	15.2	139	-.000 004	.001 124
1 113 000	700 000	.918	.009 98	16.2	134	-.000 004	.001 165	.918	.009 77	16.2	137	-.000 004	.001 140	.919	.009 59	16.2	140	-.000 004	.001 118
1 033 500	650 000	.919	.010 7	17.4	135	-.000 004	.001 157	.919	.010 4	17.4	138	-.000 004	.001 132	.919	.010 2	17.4	141	-.000 004	.001 111
954 000	600 000	.919	.011 5	18.9	136	-.000 005	.001 149	.919	.011 2	18.9	139	-.000 004	.001 124	.919	.011 0	18.9	142	-.000 004	.001 103
874 500	550 000	.919	.012 4	20.6	137	-.000 005	.001 140	.919	.012 2	20.6	140	-.000 005	.001 116	.919	.011 9	20.6	143	-.000 005	.001 095
795 000	500 000	.919	.013 5	22.5	138	-.000 005	.001 130	.919	.013 2	22.5	141	-.000 005	.001 107	.919	.012 9	22.5	144	-.000 005	.001 087
715 500	450 000	.919	.014 9	25.2	139	-.000 006	.001 120	.919	.014 6	25.2	142	-.000 006	.001 097	.919	.014 3	25.2	145	-.000 005	.001 078
636 000	400 000	.919	.016 5	28.2	141	-.000 006	.001 109	.919	.016 2	28.2	144	-.000 006	.001 087	.919	.015 9	28.2	146	-.000 006	.001 068
556 500	350 000	.919	.018 6	31.8	141	-.000 007	.001 105	.919	.018 2	31.8	144	-.000 007	.001 081	.919	.017 8	31.8	147	-.000 007	.001 062
477 000	300 000	.919	.021 4	37.1	143	-.000 008	.001 091	.919	.020 9	37.1	146	-.000 008	.001 068	.919	.020 6	37.1	149	-.000 007	.001 050
397 500	250 000	.919	.025 2	44.4	146	-.000 009	.001 074	.919	.024 7	44.4	149	-.000 009	.001 052	.919	.024 3	44.4	151	-.000 009	.001 035
336 400	0000	.918	.029 5	52.6	148	-.000 011	.001 060	.918	.028 9	52.6	151	-.000 010	.001 039	.919	.028 4	52.6	153	-.000 010	.001 021
266 800	000	.918	.036 2	66.2	152	-.000 013	.001 033	.918	.035 5	66.2	155	-.000 012	.001 013	.918	.034 9	66.2	158	-.000 012	.000 996
0000	00	.910	.047 0	87.2	171	-.000 017	.001 013	.910	.046 1	87.3	174	-.000 016	.000 993	.910	.045 3	87.3	176	-.000 015	.000 976

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT	21 FEET—6.401 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	23 FEET—7.010 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	25 FEET—7.620 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.918	.006 88	11.5	138	-.000 003	.001 134	.918	.006 77	11.5	140	-.000 003	.001 114	.918	.006 68	11.5	142	-.000 003	.001 101
1 510 500	950 000	.918	.007 19	12.1	139	-.000 003	.001 128	.918	.007 07	12.1	141	-.000 003	.001 111	.919	.006 98	12.1	143	-.000 003	.001 095
1 431 000	900 000	.919	.007 53	12.7	139	-.000 003	.001 122	.919	.007 41	12.7	141	-.000 003	.001 105	.919	.007 31	12.7	143	-.000 003	.001 089
1 351 500	850 000	.919	.007 92	13.4	140	-.000 003	.001 116	.919	.007 81	13.4	142	-.000 003	.001 101	.919	.007 69	13.4	144	-.000 003	.001 085
1 272 000	800 000	.919	.008 37	14.2	141	-.000 003	.001 113	.919	.008 24	14.2	143	-.000 003	.001 095	.919	.008 12	14.2	145	-.000 003	.001 079
1 192 500	750 000	.919	.008 85	15.2	141	-.000 003	.001 105	.919	.008 73	15.2	144	-.000 003	.001 089	.919	.008 60	15.2	146	-.000 003	.001 074
1 113 000	700 000	.919	.009 42	16.2	142	-.000 004	.001 099	.919	.009 28	16.2	144	-.000 003	.001 083	.919	.009 15	16.2	146	-.000 003	.001 068
1 033 500	650 000	.919	.010 1	17.4	143	-.000 004	.001 091	.919	.009 92	17.4	145	-.000 004	.001 076	.919	.009 79	17.4	147	-.000 004	.001 062
954 000	600 000	.919	.010 8	18.9	.144	-.000 004	.001 085	.919	.010 7	18.9	146	-.000 004	.001 070	.919	.010 5	18.9	148	-.000 004	.001 054
874 500	550 000	.919	.011 8	20.6	145	-.000 004	.001 078	.919	.011 6	20.6	147	-.000 004	.001 062	.919	.011 4	20.6	149	-.000 004	.001 046
795 000	500 000	.919	.012 7	22.5	146	-.000 005	.001 068	.919	.012 5	22.5	148	-.000 005	.001 052	.919	.012 4	22.5	150	-.000 004	.001 039
715 500	450 000	.919	.014 1	25.2	147	-.000 005	.001 060	.919	.013 9	25.2	149	-.000 005	.001 044	.919	.013 7	25.2	151	-.000 005	.001 031
636 000	400 000	.919	.015 7	28.2	149	-.000 006	.001 050	.919	.015 4	28.2	151	-.000 006	.001 035	.919	.015 2	28.2	153	-.000 005	.001 021
556 500	350 000	.919	.017 6	31.8	149	-.000 006	.001 046	.919	.017 3	31.8	151	-.000 006	.001 031	.919	.017 1	31.8	154	-.000 006	.001 017
477 000	300 000	.919	.020 3	37.1	151	-.000 007	.001 033	.919	.020 0	37.1	153	-.000 007	.001 019	.919	.019 7	37.1	155	-.000 007	.001 006
397 500	250 000	.919	.023 9	44.4	154	-.000 008	.001 019	.919	.023 6	44.4	156	-.000 008	.001 004	.919	.023 3	44.4	158	-.000 008	.000 992
336 400	0000	.919	.028 0	52.6	156	-.000 010	.001 006	.919	.027 6	52.6	158	-.000 009	.000 992	.919	.027 2	52.6	160	-.000 009	.000 978
266 800	000	.918	.034 3	66.2	160	-.000 012	.000 980	.918	.033 9	66.2	162	-.000 011	.000 969	.918	.033 5	66.2	164	-.000 011	.000 957
0000	00	.910	.044 6	87.3	179	-.000 015	.000 962	.911	.044 0	87.3	181	-.000 015	.000 949	.911	.043 6	87.3	183	-.000 014	.000 939

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

210 MILES—337.96 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

9 FEET—2.743 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.008 74	12.5	136	-.000 004	001 311
950 000	.907	.009 09	13.1	136	-.000 004	001 304
900 000	.907	.009 48	13.7	137	-.000 004	001 298
850 000	.907	.009 91	14.4	138	-.000 004	001 290
800 000	.907	.0104	15.2	138	-.000 005	001 284
750 000	.907	.0110	16.1	139	-.000 005	001 276
700 000	.907	.0116	17.2	140	-.000 005	001 268
650 000	.907	.0123	18.4	141	-.000 005	001 260
600 000	.907	.0132	19.8	142	-.000 006	001 249
550 000	.907	.0142	21.5	143	-.000 006	001 239
500 000	.907	.0154	23.6	144	-.000 007	001 229
450 000	.907	.0169	26.1	146	-.000 007	001 217
400 000	.907	.0188	29.2	148	-.000 008	001 205
350 000	.907	.0211	33.3	149	-.000 009	001 190
300 000	.907	.0242	38.7	151	-.000 010	001 174
250 000	.907	.0285	46.4	154	-.000 011	001 156
0 000	.906	.0331	54.7	157	-.000 013	001 138
000	.906	.0410	68.9	161	-.000 016	001 117
00	.906	.0507	86.7	164	.000 019	001 097

11 FEET—3.353 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.008 42	12.5	141	-.000 004	.001 262
950 000	.907	.008 75	13.1	141	-.000 004	.001 256
900 000	.907	.009 13	13.7	142	-.000 004	.001 249
850 000	.907	.009 55	14.4	143	-.000 004	.001 243
800 000	.907	.0100	15.2	143	-.000 004	.001 237
750 000	.907	.0106	16.1	144	-.000 005	.001 229
700 000	.907	.0112	17.2	145	-.000 005	.001 223
650 000	.907	.0119	18.4	146	-.000 005	.001 215
600 000	.907	.0127	19.8	147	-.000 005	.001 205
550 000	.907	.0137	21.5	148	-.000 006	.001 197
500 000	.907	.0149	23.6	150	-.000 006	.001 186
450 000	.907	.0163	26.1	151	-.000 007	.001 176
400 000	.907	.0181	29.2	153	-.000 007	.001 164
350 000	.907	.0204	33.3	154	-.000 008	.001 150
300 000	.907	.0234	38.7	156	-.000 009	.001 136
250 000	.907	.0276	46.4	159	-.000 011	.001 119
0 000	.906	.0321	54.7	162	-.000 012	.001 101
000	.906	.0396	68.9	166	-.000 015	.001 081
00	.906	.0491	86.7	16[illegible]	.000 018	.001 062

13 FEET—3.962 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.008 17	12.5	145	-.000 003	.001 225
950 000	.907	.00850	13.1	145	-.000 004	.001 219
900 000	.907	.008 86	13.7	146	-.000 004	.001 213
850 000	.907	.009 27	14.4	147	-.000 004	.001 207
800 000	.907	.009 74	15.2	148	-.000 004	.001 201
750 000	.907	.0103	16.1	148	-.000 004	.001 195
700 000	.907	.0109	17.2	149	-.000 004	.001 186
650 000	.907	.0116	18.4	150	-.000 005	.001 178
600 000	.907	.0124	19.8	151	-.000 005	.001 170
550 000	.907	.0133	21.5	152	-.000 005	.001 162
500 000	.907	.0145	23.6	154	-.000 006	.001 154
450 000	.907	.0159	26.1	155	-.000 006	.001 144
400 000	.907	.0176	29.2	157	-.000 007	.001 131
350 000	.907	.0198	33.3	159	-.000 008	.001 119
300 000	.907	.0228	38.7	160	-.000 009	.001 105
250 000	.907	.0269	46.4	163	-.000 010	.001 089
0 000	.907	.0312	54.7	166	-.000 012	.001 072
000	.906	.0386	68.9	170	-.000 014	.001 054
00	.906	.0478	86.7	173	-.000 017	.001 036

15 FEET—4.572 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.007 97	12.5	148	-.000 003	.001 195
950 000	.907	.008 28	13.1	149	-.000 003	.001 188
900 000	.907	.008 64	13.7	150	-.000 004	.001 182
850 000	.907	.009 05	14.4	150	-.000 004	.001 178
800 000	.907	.009 51	15.2	151	-.000 004	.001 172
750 000	.907	.0100	16.1	152	-.000 004	.001 164
700 000	.907	.0106	17.2	153	-.000 004	.001 158
650 000	.907	.0113	18.4	154	-.000 005	.001 152
600 000	.907	.0121	19.8	155	-.000 005	.001 144
550 000	.907	.0130	21.5	156	-.000 005	.001 136
500 000	.907	.0141	23.6	157	-.000 006	.001 125
450 000	.907	.0155	26.1	158	-.000 006	.001 117
400 000	.907	.0172	29.2	160	-.000 007	.001 105
350 000	.907	.0194	33.3	162	-.000 007	.001 093
300 000	.907	.0223	38.7	164	-.000 008	.001 081
250 000	.907	.0263	46.4	166	-.000 010	.001 064
0 000	.907	.0306	54.7	170	-.000 011	.001 050
000	.907	.0378	68.9	173	-.000 014	.001 032
00	.907	.0468	86.7	176	-.000 017	.001 013

17 FEET—5.182 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.007 79	12.5	151	-.000 003	.001 168
950 000	.907	.008 11	13.1	152	-.000 003	.001 164
900 000	.907	.008 46	13.7	153	-.000 003	.001 158
850 000	.907	.008 85	14.4	153	-.000 004	.001 152
800 000	.907	.009 31	15.2	154	-.000 004	.001 148
750 000	.907	.009 81	16.1	155	-.000 004	.001 142
700 000	.907	.0104	17.2	156	-.000 004	.001 133
650 000	.907	.0111	18.4	157	-.000 004	.001 127
600 000	.907	.0118	19.8	158	-.000 005	.001 119
550 000	.907	.0127	21.5	159	-.000 005	.001 111
500 000	.907	.0139	23.6	160	-.000 005	.001 103
450 000	.907	.0152	26.1	162	-.000 006	.001 095
400 000	.907	.0169	29.2	163	-.000 006	.001 083
350 000	.907	.0190	33.3	165	-.000 007	.001 072
300 000	.907	.0218	38.7	167	-.000 008	.001 058
250 000	.907	.0258	46.4	170	-.000 009	.001 044
0 000	.907	.0300	54.7	173	-.000 011	.001 030
000	.907	.0371	68.9	176	-.000 013	.001 011
00	.907	.0460	86.7	17[illegible]	.000 016	.000 995

19 FEET—5.791 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.907	.007 66	12.5	154	-.000 003	.001 148
950 000	.907	.007 96	13.1	155	-.000 003	.001 142
900 000	.907	.008 31	13.7	155	-.000 003	.001 138
850 000	.907	.008 69	14.4	156	-.000 003	.001 131
800 000	.907	.009 12	15.2	157	-.000 004	.001 125
750 000	.907	.009 62	16.1	158	-.000 004	.001 119
700 000	.907	.0102	17.2	159	-.000 004	.001 113
650 000	.908	.0109	18.4	159	-.000 004	.001 107
600 000	.907	.0116	19.8	161	-.000 004	.001 099
550 000	.907	.0125	21.5	162	-.000 005	.001 093
500 000	.907	.0136	23.6	163	-.000 005	.001 085
450 000	.907	.0149	26.1	164	-.000 006	.001 074
400 000	.907	.0166	29.2	166	-.000 006	.001 064
350 000	.907	.0187	33.3	168	-.000 007	.001 054
300 000	.907	.0215	38.7	170	-.000 008	.001 042
250 000	.907	.0254	46.4	172	-.000 009	.001 028
0 000	.907	.0295	54.7	176	-.000 010	.001 013
000	.907	.0365	68.9	179	-.000 013	.000 995
00	.907	.0452	86.7	182	-.000 015	.000 979

21 FEET—6.401 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.908	.007 52	12.5	157	-.000 003	.001 127
950 000	.908	.007 83	13.1	157	-.000 003	.001 123
900 000	.908	.008 18	13.7	158	-.000 003	.001 119
850 000	.908	.008 55	14.4	159	-.000 003	.001 113
800 000	.908	.008 98	15.2	159	-.000 003	.001 107
750 000	.908	.009 46	16.1	160	-.000 004	.001 101
700 000	.908	.0100	17.2	161	-.000 004	.001 095
650 000	.908	.0107	18.4	162	-.000 004	.001 089
600 000	.908	.0114	19.8	163	-.000 004	.001 083
550 000	.908	.0123	21.5	164	-.000 005	.001 074
500 000	.908	.0134	23.6	165	-.000 005	.001 066
450 000	.908	.0147	26.1	167	-.000 005	.001 058
400 000	.908	.0163	29.2	169	-.000 006	.001 048
350 000	.908	.0184	33.3	170	-.000 007	.001 038
300 000	.908	.0212	38.7	172	-.000 008	.001 026
250 000	.908	.0250	46.4	175	-.000 009	.001 011
0 000	.907	.0290	54.7	178	-.000 010	.000 997
000	.907	.0360	68.9	181	-.000 012	.000 981
00	.907	.0446	86.7	185	-.000 015	.000 965

23 FEET—7.010 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.908	.007 41	12.5	159	-.000 003	.001 111
950 000	.908	.007 72	13.1	159	-.000 003	.001 107
900 000	.908	.008 06	13.7	160	-.000 003	.001 103
850 000	.908	.008 43	14.4	161	-.000 003	.001 097
800 000	.908	.008 85	15.2	162	-.000 003	.001 091
750 000	.908	.009 34	16.1	162	-.000 004	.001 087
700 000	.908	.009 89	17.2	163	-.000 004	.001 081
650 000	.908	.0105	18.4	164	-.000 004	.001 074
600 000	.908	.0113	19.8	165	-.000 004	.001 066
550 000	.908	.0122	21.5	166	-.000 004	.001 060
500 000	.908	.0132	23.6	168	-.000 005	.001 052
450 000	.908	.0145	26.1	169	-.000 005	.001 044
400 000	.908	.0161	29.2	171	-.000 006	.001 034
350 000	.908	.0181	33.3	173	-.000 006	.001 024
300 000	.908	.0209	38.7	174	-.000 007	.001 011
250 000	.908	.0247	46.4	177	-.000 009	.000 999
0 000	.907	.0287	54.7	180	-.000 010	.000 985
000	.907	.0355	68.9	184	-.000 012	.000 969
00	.907	.0440	86.7	187	-.000 015	.000 952

25 FEET—7.620 METERS

Circular Mils or A W G (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1000 000	.908	.007 32	12.5	161	-.000 003	.001 097
950 000	.908	.007 62	13.1	162	-.000 003	.001 093
900 000	.908	.007 94	13.7	162	-.000 003	.001 087
850 000	.908	.008 32	14.4	163	-.000 003	.001 083
800 000	.908	.008 73	15.2	164	-.000 003	.001 077
750 000	.908	.009 22	16.1	164	-.000 003	.001 072
700 000	.908	.009 76	17.2	165	-.000 004	.001 066
650 000	.908	.0104	18.4	166	-.000 004	.001 060
600 000	.908	.0111	19.8	167	-.000 004	.001 054
550 000	.908	.0120	21.5	169	-.000 004	.001 046
500 000	.908	.0130	23.6	170	-.000 005	.001 038
450 000	.908	.0143	26.1	171	-.000 005	.001 030
400 000	.908	.0159	29.2	173	-.000 006	.001 022
350 000	.908	.0179	33.3	175	-.000 006	.001 011
300 000	.908	.0206	38.7	177	-.000 007	.000 999
250 000	.908	.0244	46.4	179	-.000 008	.000 987
0 000	.907	.0283	54.7	182	-.000 010	.000 973
000	.907	.0351	68.9	186	-.000 012	.000 956
00	.907	.0435	86.7	189	-.000 014	.000 942

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

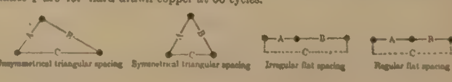


TABLE LXXVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

210 MILES—337.96 Km.

CIRCULAR MILS OR A. W. G. (B & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★ 9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.910	.008 85	12.0	124	-.000 004	.001 389	.910	.008 51	12.0	129	-.000 004	.001 336	.910	.008 24	12.0	133	-.000 004	.001 293
1 510 500	950 000	.910	.009 25	12.6	124	-.000 004	.001 382	.910	.008 88	12.6	129	-.000 004	.001 327	.910	.008 61	12.6	133	-.000 004	.001 287
1 431 000	900 000	.910	.009 68	13.2	125	-.000 005	.001 374	.910	.009 31	13.2	130	-.000 004	.001 321	.910	.009 02	13.2	134	-.000 004	.001 281
1 351 500	850 000	.910	.010 2	14.0	126	-.000 005	.001 366	.910	.009 78	14.0	131	-.000 004	.001 313	.910	.009 47	14.0	135	-.000 004	.001 273
1 272 000	800 000	.910	.010 7	14.8	126	-.000 005	.001 358	.910	.010 3	14.8	131	-.000 005	.001 307	.910	.010 0	14.8	136	-.000 004	.001 266
1 192 500	750 000	.910	.011 4	15.8	127	-.000 005	.001 350	.910	.010 9	15.8	132	-.000 005	.001 299	.910	.010 6	15.8	136	-.000 005	.001 258
1 113 000	700 000	.910	.012 1	16.9	128	-.000 006	.001 342	.910	.011 6	16.9	133	-.000 005	.001 291	.910	.011 3	16.9	137	-.000 005	.001 252
1 033 500	650 000	.910	.012 9	18.2	129	-.000 006	.001 332	.910	.012 4	18.2	134	-.000 006	.001 281	.910	.012 0	18.2	138	-.000 005	.001 242
954 000	600 000	.910	.013 8	19.7	130	-.000 006	.001 321	.910	.013 3	19.7	135	-.000 006	.001 273	.910	.012 9	19.7	139	-.000 006	.001 234
874 500	550 000	.910	.015 0	21.5	131	-.000 007	.001 309	.910	.014 4	21.5	136	-.000 006	.001 260	.910	.014 0	21.5	140	-.000 006	.001 224
795 000	500 000	.910	.016 2	23.5	132	-.000 007	.001 299	.910	.015 6	23.5	137	-.000 007	.001 250	.910	.015 2	23.5	141	-.000 006	.001 213
715 500	450 000	.910	.017 9	26.2	133	-.000 008	.001 285	.910	.017 3	26.2	138	-.000 007	.001 240	.910	.016 8	26.2	142	-.000 007	.001 201
636 000	400 000	.910	.019 9	29.4	135	-.000 009	.001 270	.910	.019 2	29.4	140	-.000 008	.001 226	.910	.018 6	29.4	144	-.000 008	.001 189
556 500	350 000	.910	.022 3	33.2	136	-.000 010	.001 266	.910	.021 5	33.2	140	-.000 009	.001 220	.910	.020 9	33.2	144	-.000 009	.001 185
477 000	300 000	.910	.025 7	38.7	137	-.000 011	.001 248	.910	.024 8	38.7	142	-.000 010	.001 203	.910	.024 1	38.7	147	-.000 010	.001 171
397 500	250 000	.910	.030 3	46.4	140	-.000 013	.001 228	.910	.029 3	46.4	145	-.000 012	.001 185	.910	.028 4	46.4	149	-.000 011	.001 152
336 400	0 000	.910	.035 3	54.9	142	-.000 015	.001 209	.910	.034 1	54.9	147	-.000 014	.001 169	.910	.033 2	54.9	151	-.000 013	.001 136
266 800	000	.910	.043 3	69.1	147	-.000 018	.001 177	.910	.041 8	69.1	152	-.000 017	.001 136	.910	.040 7	69.1	156	-.000 016	.001 108
0 000	00	.900	.056 1	91.0	166	-.000 023	.001 151	.900	.054 2	91.0	171	-.000 021	.001 112	.901	.052 8	91.0	175	-.000 020	.001 084

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.910	.008 02	12.0	136	-.000 004	.001 258	.910	.007 84	12.0	140	-.000 003	.001 230	.910	.007 70	12.0	142	-.000 003	.001 207
1 510 500	950 000	.910	.008 38	12.6	137	-.000 004	.001 252	.910	.008 20	12.6	140	-.000 004	.001 226	.910	.008 04	12.6	143	-.000 003	.001 201
1 431 000	900 000	.910	.008 78	13.2	138	-.000 004	.001 246	.910	.008 59	13.2	141	-.000 004	.001 220	.910	.008 42	13.2	143	-.000 004	.001 195
1 351 500	850 000	.910	.009 23	14.0	138	-.000 004	.001 240	.910	.009 04	14.0	141	-.000 004	.001 213	.910	.008 85	14.0	144	-.000 004	.001 189
1 272 000	800 000	.910	.009 74	14.8	139	-.000 004	.001 234	.910	.009 53	14.8	142	-.000 004	.001 207	.910	.009 34	14.8	145	-.000 004	.001 183
1 192 500	750 000	.910	.010 3	15.8	140	-.000 004	.001 226	.910	.010 1	15.8	143	-.000 004	.001 199	.910	.009 90	15.8	146	-.000 004	.001 177
1 113 000	700 000	.910	.011 0	16.9	141	-.000 005	.001 220	.910	.010 7	16.9	144	-.000 004	.001 193	.910	.010 5	16.9	146	-.000 004	.001 171
1 033 500	650 000	.910	.011 7	18.2	141	-.000 005	.001 211	.910	.011 5	18.2	145	-.000 005	.001 185	.910	.011 3	18.2	147	-.000 005	.001 163
954 000	600 000	.910	.012 6	19.7	142	-.000 005	.001 203	.910	.012 3	19.7	146	-.000 005	.001 177	.910	.012 1	19.7	148	-.000 005	.001 154
874 500	550 000	.910	.013 7	21.5	143	-.000 006	.001 193	.910	.013 4	21.5	147	-.000 005	.001 169	.910	.013 1	21.5	149	-.000 005	.001 146
795 000	500 000	.910	.014 8	23.5	145	-.000 006	.001 183	.911	.014 5	23.5	148	-.000 006	.001 158	.911	.014 2	23.5	150	-.000 006	.001 138
715 500	450 000	.910	.016 4	26.2	146	-.000 007	.001 173	.910	.016 0	26.2	149	-.000 006	.001 148	.910	.015 8	26.2	152	-.000 006	.001 128
636 000	400 000	.910	.018 2	29.4	147	-.000 007	.001 161	.910	.017 8	29.4	151	-.000 007	.001 138	.910	.017 5	29.4	153	-.000 007	.001 118
556 500	350 000	.910	.020 4	33.2	148	-.000 008	.001 156	.910	.020 0	33.2	151	-.000 008	.001 132	.910	.019 6	33.2	154	-.000 008	.001 112
477 000	300 000	.910	.023 5	38.7	150	-.000 009	.001 142	.910	.023 0	38.7	153	-.000 009	.001 118	.910	.022 6	38.7	156	-.000 009	.001 099
397 500	250 000	.910	.027 7	46.4	153	-.000 011	.001 124	.910	.027 2	46.4	156	-.000 010	.001 101	.910	.026 7	46.4	158	-.000 010	.001 083
336 400	0 000	.910	.032 4	54.9	155	-.000 013	.001 110	.910	.031 8	54.9	158	-.000 012	.001 087	.910	.031 2	54.9	161	-.000 012	.001 069
266 800	000	.910	.039 8	69.1	159	-.000 015	.001 081	.910	.039 0	69.1	162	-.000 014	.001 061	.910	.038 3	69.1	165	-.000 014	.001 042
0 000	00	.901	.051 6	91.0	179	-.000 019	.001 060	.901	.050 7	91.1	182	-.000 018	.001 040	.901	.049 8	91.1	185	-.000 018	.001 022

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.910	.007 57	12.0	145	-.000 003	.001 187	.910	.007 44	12.0	147	-.000 003	.001 167	.910	.007 35	12.0	149	-.000 003	.001 152
1 510 500	950 000	.910	.007 90	12.6	145	-.000 003	.001 181	.910	.007 78	12.6	147	-.000 003	.001 163	.910	.007 67	12.6	149	-.000 003	.001 146
1 431 000	900 000	.910	.008 28	13.2	146	-.000 003	.001 175	.910	.008 15	13.2	148	-.000 003	.001 156	.910	.008 04	13.2	150	-.000 003	.001 140
1 351 500	850 000	.910	.008 70	14.0	146	-.000 004	.001 169	.910	.008 58	14.0	149	-.000 003	.001 152	.910	.008 46	14.0	151	-.000 003	.001 136
1 272 000	800 000	.910	.009 20	14.8	147	-.000 004	.001 165	.910	.009 05	14.8	149	-.000 004	.001 146	.910	.008 92	14.8	152	-.000 004	.001 130
1 192 500	750 000	.910	.009 73	15.8	148	-.000 004	.001 156	.910	.009 59	15.8	150	-.000 004	.001 140	.910	.009 45	15.8	152	-.000 004	.001 124
1 113 000	700 000	.910	.010 4	16.9	149	-.000 004	.001 150	.910	.010 2	16.9	151	-.000 004	.001 134	.910	.010 1	16.9	153	-.000 004	.001 118
1 033 500	650 000	.910	.011 1	18.2	150	-.000 004	.001 142	.910	.010 9	18.2	152	-.000 004	.001 126	.910	.010 8	18.2	154	-.000 004	.001 112
954 000	600 000	.910	.011 9	19.7	151	-.000 005	.001 136	.910	.011 7	19.7	153	-.000 005	.001 120	.911	.011 6	19.7	155	-.000 004	.001 104
874 500	550 000	.910	.012 9	21.5	152	-.000 005	.001 128	.910	.012 7	21.5	154	-.000 005	.001 112	.911	.012 5	21.5	156	-.000 005	.001 095
795 000	500 000	.911	.014 0	23.5	153	-.000 005	.001 118	.911	.013 8	23.5	155	-.000 005	.001 101	.911	.013 6	23.5	157	-.000 005	.001 087
715 500	450 000	.911	.015 5	26.2	154	-.000 006	.001 110	.911	.015 3	26.2	156	-.000 006	.001 093	.910	.015 1	26.2	158	-.000 006	.001 079
636 000	400 000	.910	.017 2	29.4	156	-.000 007	.001 099	.911	.017 0	29.4	158	-.000 006	.001 083	.910	.016 7	29.4	160	-.000 006	.001 069
556 500	350 000	.910	.019 3	33.2	156	-.000 007	.001 095	.911	.019 0	33.2	158	-.000 007	.001 079	.910	.018 8	33.2	161	-.000 007	.001 065
477 000	300 000	.910	.022 3	38.7	158	-.000 008	.001 081	.910	.022 0	38.7	161	-.000 008	.001 067	.910	.021 7	38.7	163	-.000 008	.001 053
397 500	250 000	.910	.026 3	46.4	161	-.000 010	.001 067	.910	.025 9	46.4	163	-.000 009	.001 051	.910	.025 6	46.4	165	-.000 009	.001 038
336 400	0 000	.910	.030 7	54.9	163	-.000 011	.001 053	.910	.030 3	54.9	165	-.000 011	.001 038	.910	.029 9	54.9	168	-.000 011	.001 024
266 800	000	.910	.037 7	69.1	167	-.000 013	.001 026	.910	.037 3	69.1	170	-.000 013	.001 014	.910	.036 8	69.1	172	-.000 013	.001 002
0 000	00	.901	.049 1	91.1	187	-.000 017	.001 007	.902	.048 4	91.1	189	-.000 017	.000 993	.902	.047 9	91.1	191	-.000 016	.000 983

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXXIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

220 MILES—354.06 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

9 FEET—2.743 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.009 57	13.0	142	−.000 005	.001 369
950 000	.898	.009 95	13.6	142	−.000 005	.001 363
900 000	.898	.010 4	14.3	143	−.000 005	.001 356
850 000	.898	.010 8	15.0	144	−.000 005	.001 348
800 000	.898	.011 4	15.9	145	−.000 005	.001 342
750 000	.898	.012 0	16.8	145	−.000 006	.001 333
700 000	.898	.012 7	17.9	146	−.000 006	.001 324
650 000	.898	.013 5	19.2	147	−.000 006	.001 316
600 000	.898	.014 4	20.7	149	−.000 007	.001 305
550 000	.898	.015 5	22.4	150	−.000 007	.001 295
500 000	.898	.016 9	24.6	151	−.000 008	.001 284
450 000	.898	.018 5	27.2	152	−.000 008	.001 271
400 000	.898	.020 5	30.4	154	−.000 009	.001 259
350 000	.898	.023 1	34.7	156	−.000 010	.001 244
300 000	.898	.026 5	40.3	158	−.000 011	.001 227
250 000	.898	.031 2	48.3	161	−.000 013	.001 208
0 000	.897	.036 3	56.9	164	−.000 015	.001 188
000	.897	.044 8	71.7	168	−.000 018	.001 167
00	.897	.055 4	90.3	171	−.000 022	.001 146

11 FEET—3.353 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.009 21	13.0	147	−.000 004	.001 318
950 000	.898	.009 58	13.6	148	−.000 004	.001 312
900 000	.898	.009 99	14.3	148	−.000 005	.001 305
850 000	.898	.010 5	15.0	149	−.000 005	.001 299
800 000	.898	.011 0	15.9	150	−.000 005	.001 293
750 000	.898	.011 6	16.8	151	−.000 005	.001 284
700 000	.898	.012 2	17.9	151	−.000 005	.001 278
650 000	.898	.013 0	19.2	153	−.000 006	.001 269
600 000	.898	.013 9	20.7	154	−.000 006	.001 259
550 000	.898	.015 0	22.4	155	−.000 007	.001 250
500 000	.898	.016 3	24.6	156	−.000 007	.001 239
450 000	.898	.017 9	27.2	157	−.000 008	.001 229
400 000	.898	.019 8	30.4	159	−.000 008	.001 216
350 000	.898	.022 3	34.7	161	−.000 009	.001 201
300 000	.898	.025 6	40.3	163	−.000 011	.001 186
250 000	.898	.030 3	48.3	166	−.000 012	.001 169
0 000	.898	.035 1	56.9	170	−.000 014	.001 150
000	.898	.043 4	71.7	173	−.000 017	.001 129
00	.897	.053 7	90.3	177	−.000 021	.001 110

13 FEET—3.962 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.008 94	13.0	151	−.000 004	.001 280
950 000	.898	.009 29	13.6	152	−.000 004	.001 273
900 000	.898	.009 69	14.3	152	−.000 004	.001 267
850 000	.898	.010 1	15.0	153	−.000 004	.001 261
800 000	.898	.010 7	15.9	154	−.000 005	.001 254
750 000	.898	.011 2	16.8	155	−.000 005	.001 248
700 000	.898	.011 9	17.9	156	−.000 005	.001 239
650 000	.898	.012 6	19.2	157	−.000 005	.001 231
600 000	.898	.013 5	20.7	158	−.000 006	.001 222
550 000	.898	.014 6	22.4	159	−.000 006	.001 214
500 000	.898	.015 9	24.6	160	−.000 007	.001 205
450 000	.898	.017 4	27.2	162	−.000 007	.001 195
400 000	.898	.019 3	30.4	164	−.000 008	.001 182
350 000	.898	.021 7	34.7	166	−.000 009	.001 169
300 000	.898	.024 9	40.3	168	−.000 010	.001 154
250 000	.898	.029 4	48.3	170	−.000 012	.001 137
0 000	.898	.034 2	56.9	174	−.000 013	.001 120
000	.898	.042 3	71.7	177	−.000 016	.001 101
00	.897	.052 3	90.3	181	−.000 020	.001 082

15 FEET—4.572 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.008 72	13.0	155	−.000 004	.001 248
950 000	.898	.009 06	13.6	156	−.000 004	.001 242
900 000	.898	.009 45	14.3	156	−.000 004	.001 235
850 000	.898	.009 90	15.0	157	−.000 004	.001 231
800 000	.898	.010 4	15.9	158	−.000 004	.001 225
750 000	.898	.010 9	16.8	159	−.000 005	.001 216
700 000	.898	.011 6	17.9	160	−.000 005	.001 210
650 000	.898	.012 4	19.2	161	−.000 005	.001 203
600 000	.898	.013 2	20.7	162	−.000 006	.001 195
550 000	.898	.014 2	22.4	163	−.000 006	.001 186
500 000	.898	.015 5	24.6	164	−.000 006	.001 176
450 000	.898	.017 0	27.2	166	−.000 007	.001 167
400 000	.898	.018 8	30.4	168	−.000 008	.001 154
350 000	.898	.021 2	34.7	169	−.000 008	.001 142
300 000	.898	.024 4	40.3	171	−.000 010	.001 129
250 000	.898	.028 8	48.3	174	−.000 011	.001 112
0 000	.898	.033 5	56.9	178	−.000 013	.001 097
000	.898	.041 4	71.7	181	−.000 016	.001 078
00	.898	.051 2	90.3	185	−.000 019	.001 059

17 FEET—5.182 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.008 52	13.0	158	−.000 004	.001 220
950 000	.898	.008 88	13.6	159	−.000 004	.001 216
900 000	.898	.009 26	14.3	160	−.000 004	.001 210
850 000	.898	.009 68	15.0	160	−.000 004	.001 203
800 000	.898	.010 2	15.9	161	−.000 004	.001 199
750 000	.898	.010 7	16.8	162	−.000 004	.001 193
700 000	.899	.011 4	17.9	163	−.000 005	.001 184
650 000	.899	.012 1	19.2	164	−.000 005	.001 178
600 000	.899	.012 9	20.7	165	−.000 005	.001 169
550 000	.899	.013 9	22.4	166	−.000 006	.001 161
500 000	.899	.015 2	24.6	167	−.000 006	.001 152
450 000	.899	.016 6	27.2	169	−.000 007	.001 144
400 000	.899	.018 4	30.4	171	−.000 007	.001 131
350 000	.899	.020 8	34.7	172	−.000 008	.001 120
300 000	.899	.023 9	40.3	174	−.000 009	.001 106
250 000	.898	.028 2	48.3	177	−.000 011	.001 091
0 000	.898	.032 8	56.9	181	−.000 012	.001 076
000	.898	.040 6	71.7	184	−.000 015	.001 057
00	.898	.050 3	90.3	188	−.000 018	.001 040

19 FEET—5.791 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.898	.008 38	13.0	161	−.000 004	.001 199
950 000	.899	.008 71	13.6	162	−.000 004	.001 193
900 000	.899	.009 09	14.3	162	−.000 004	.001 188
850 000	.899	.009 51	15.0	163	−.000 004	.001 182
800 000	.899	.009 98	15.9	164	−.000 004	.001 176
750 000	.899	.010 5	16.8	165	−.000 004	.001 169
700 000	.899	.011 1	17.9	166	−.000 005	.001 163
650 000	.899	.011 9	19.2	167	−.000 005	.001 157
600 000	.899	.012 7	20.7	168	−.000 005	.001 148
550 000	.899	.013 7	22.4	169	−.000 005	.001 142
500 000	.899	.014 9	24.6	170	−.000 006	.001 133
450 000	.899	.016 3	27.2	172	−.000 006	.001 123
400 000	.899	.018 1	30.4	174	−.000 007	.001 112
350 000	.899	.020 4	34.7	175	−.000 008	.001 101
300 000	.899	.023 5	40.3	177	−.000 009	.001 089
250 000	.899	.027 8	48.3	180	−.000 010	.001 074
0 000	.898	.032 3	56.9	184	−.000 012	.001 059
000	.898	.039 9	71.7	187	−.000 015	.001 040
00	.898	.049 5	90.3	191	−.000 018	.001 023

21 FEET—6.401 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.899	.008 23	13.0	164	−.000 003	.001 178
950 000	.899	.008 57	13.6	164	−.000 004	.001 174
900 000	.899	.008 95	14.3	165	−.000 004	.001 169
850 000	.899	.009 36	15.0	166	−.000 004	.001 163
800 000	.899	.009 82	15.9	167	−.000 004	.001 157
750 000	.899	.010 4	16.8	167	−.000 004	.001 150
700 000	.899	.011 0	17.9	168	−.000 004	.001 144
650 000	.899	.011 7	19.2	169	−.000 005	.001 137
600 000	.899	.012 5	20.7	170	−.000 005	.001 131
550 000	.899	.013 5	22.4	171	−.000 005	.001 123
500 000	.899	.014 7	24.6	173	−.000 006	.001 114
450 000	.899	.016 1	27.2	174	−.000 006	.001 106
400 000	.899	.017 9	30.4	176	−.000 007	.001 095
350 000	.899	.020 1	34.7	178	−.000 008	.001 084
300 000	.899	.023 1	40.3	180	−.000 009	.001 072
250 000	.899	.027 3	48.3	182	−.000 010	.001 057
0 000	.898	.031 8	56.9	186	−.000 012	.001 042
000	.898	.039 4	71.7	190	−.000 014	.001 025
00	.898	.048 8	90.3	193	−.000 017	.001 008

23 FEET—7.010 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.899	.008 11	13.0	166	−.000 003	.001 161
950 000	.899	.008 44	13.6	167	−.000 003	.001 157
900 000	.899	.008 82	14.3	167	−.000 004	.001 152
850 000	.899	.009 22	15.0	168	−.000 004	.001 146
800 000	.899	.009 68	15.9	169	−.000 004	.001 140
750 000	.899	.010 2	16.8	170	−.000 004	.001 135
700 000	.899	.010 8	17.9	171	−.000 004	.001 129
650 000	.899	.011 5	19.2	171	−.000 005	.001 123
600 000	.899	.012 3	20.7	173	−.000 005	.001 114
550 000	.899	.013 3	22.4	174	−.000 005	.001 108
500 000	.899	.014 5	24.6	175	−.000 006	.001 099
450 000	.899	.015 9	27.2	177	−.000 006	.001 091
400 000	.899	.017 6	30.4	179	−.000 007	.001 080
350 000	.899	.019 9	34.7	180	−.000 007	.001 069
300 000	.899	.022 8	40.3	182	−.000 008	.001 057
250 000	.899	.027 0	48.3	185	−.000 010	.001 044
0 000	.898	.031 4	56.9	189	−.000 011	.001 029
000	.898	.038 9	71.7	192	−.000 014	.001 012
00	.898	.048 1	90.3	195	−.000 017	.000 995

25 FEET—7.620 METERS

Circular Mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.899	.008 01	13.0	168	−.000 003	.001 146
950 000	.899	.008 33	13.6	169	−.000 003	.001 142
900 000	.899	.008 69	14.3	169	−.000 003	.001 135
850 000	.899	.009 10	15.0	170	−.000 004	.001 131
800 000	.899	.009 55	15.9	171	−.000 004	.001 125
750 000	.899	.010 1	16.8	172	−.000 004	.001 120
700 000	.899	.010 7	17.9	173	−.000 004	.001 114
650 000	.899	.011 4	19.2	174	−.000 004	.001 108
600 000	.899	.012 2	20.7	175	−.000 005	.001 101
550 000	.899	.013 1	22.4	176	−.000 005	.001 093
500 000	.899	.014 3	24.6	177	−.000 005	.001 084
450 000	.899	.015 6	27.2	179	−.000 006	.001 076
400 000	.899	.017 4	30.4	181	−.000 007	.001 067
350 000	.899	.019 6	34.7	182	−.000 007	.001 057
300 000	.899	.022 5	40.3	184	−.000 008	.001 044
250 000	.899	.026 7	48.3	187	−.000 010	.001 031
0 000	.898	.031 0	56.9	191	−.000 011	.001 016
000	.898	.038 4	71.7	194	−.000 013	.000 999
00	.898	.047 6	90.3	198	−.000 016	.000 984

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} - \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE LXXX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

220 MILES—354.06 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.901	.00968	12.5	129	-.000005	.001 451	.901	.00931	12.5	134	-.000005	.001 395	.901	.00902	12.5	139	-.000004	.001 351
1 510 500	950 000	.901	.0101	13.1	130	-.000005	.001 444	.901	.00971	13.1	135	-.000005	.001 387	.901	.00942	13.1	139	-.000004	.001 344
1 431 000	900 000	.902	.0106	13.8	131	-.000005	.001 436	.902	.0102	13.8	136	-.000005	.001 380	.902	.00987	13.8	140	-.000005	.001 338
1 351 500	850 000	.902	.0111	14.6	131	-.000006	.001 427	.902	.0107	14.6	136	-.000005	.001 372	.902	.0104	14.6	141	-.000005	.001 329
1 272 000	800 000	.902	.0117	15.5	132	-.000006	.001 419	.902	.0113	15.5	137	-.000005	.001 366	.902	.0109	15.5	142	-.000005	.001 323
1 192 500	750 000	.902	.0124	16.5	133	-.000006	.001 410	.902	.0120	16.5	138	-.000006	.001 357	.902	.0116	16.5	142	-.000005	.001 314
1 113 000	700 000	.902	.0132	17.6	134	-.000006	.001 402	.902	.0127	17.6	139	-.000006	.001 349	.902	.0123	17.6	143	-.000006	.001 308
1 033 500	650 000	.902	.0141	19.0	135	-.000007	.001 391	.902	.0136	19.0	140	-.000006	.001 338	.902	.0132	19.0	144	-.000006	.001 297
954 000	600 000	.902	.0151	20.5	136	-.000007	.001 380	.902	.0146	20.5	141	-.000007	.001 329	.902	.0141	20.5	145	-.000006	.001 289
874 500	550 000	.902	.0164	22.4	136	-.000008	.001 368	.902	.0158	22.4	142	-.000007	.001 317	.902	.0153	22.4	146	-.000007	.001 278
795 000	500 000	.902	.0178	24.5	138	-.000008	.001 357	.902	.0171	24.5	143	-.000008	.001 306	.902	.0166	24.5	147	-.000007	.001 268
715 500	450 000	.902	.0196	27.3	139	-.000009	.001 342	.902	.0190	27.3	144	-.000009	.001 295	.902	.0184	27.3	149	-.000008	.001 255
636 000	400 000	.902	.0218	30.6	141	-.000010	.001 327	.902	.0210	30.6	146	-.000009	.001 280	.902	.0204	30.6	150	-.000009	.001 242
556 500	350 000	.902	.0244	34.5	142	-.000011	.001 323	.902	.0235	34.5	147	-.000010	.001 274	.902	.0229	34.5	151	-.000010	.001 238
477 000	300 000	.902	.0281	40.3	144	-.000013	.001 304	.902	.0271	40.3	149	-.000012	.001 257	.902	.0264	40.3	153	-.000011	.001 223
397 500	250 000	.902	.0331	48.3	146	-.000015	.001 283	.902	.0320	48.3	152	-.000014	.001 238	.902	.0311	48.3	156	-.000013	.001 204
336 400	0 000	.901	.0386	57.1	149	-.000017	.001 263	.901	.0373	57.1	154	-.000016	.001 221	.902	.0363	57.1	158	-.000015	.001 187
266 800	000	.901	.0473	71.9	153	-.000020	.001 229	.901	.0457	71.9	158	-.000019	.001 187	.901	.0445	71.9	163	-.000018	.001 157
0 000	00	.890	.0613	94.7	174	-.000026	.001 202	.891	.0593	94.7	179	-.000024	.001 162	.891	.0578	94.7	183	-.000023	.001 132

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.901	.00877	12.5	143	-.000004	.001 314	.902	.00858	12.5	146	-.000004	.001 285	.901	.00842	12.5	149	-.000004	.001 261
1 510 500	950 000	.901	.00916	13.1	143	-.000004	.001 308	.902	.00897	13.1	146	-.000004	.001 280	.902	.00879	13.1	149	-.000004	.001 255
1 431 000	900 000	.902	.00961	13.8	144	-.000004	.001 302	.902	.00940	13.8	147	-.000004	.001 274	.902	.00921	13.8	150	-.000004	.001 249
1 351 500	850 000	.902	.0101	14.6	145	-.000005	.001 295	.902	.00989	14.6	148	-.000004	.001 268	.902	.00969	14.6	151	-.000004	.001 242
1 272 000	800 000	.902	.0107	15.5	145	-.000005	.001 289	.902	.0104	15.5	149	-.000005	.001 261	.902	.0102	15.5	151	-.000004	.001 236
1 192 500	750 000	.902	.0113	16.5	146	-.000005	.001 280	.902	.0110	16.5	149	-.000005	.001 253	.902	.0108	16.5	152	-.000005	.001 229
1 113 000	700 000	.902	.0120	17.6	147	-.000005	.001 274	.902	.0118	17.6	150	-.000005	.001 246	.902	.0115	17.6	153	-.000005	.001 223
1 033 500	650 000	.902	.0128	19.0	148	-.000006	.001 266	.902	.0126	19.0	151	-.000005	.001 238	.902	.0123	19.0	154	-.000005	.001 215
954 000	600 000	.902	.0138	20.5	149	-.000006	.001 257	.902	.0135	20.5	152	-.000006	.001 229	.902	.0132	20.5	155	-.000006	.001 206
874 500	550 000	.902	.0149	22.4	150	-.000007	.001 246	.902	.0146	22.4	153	-.000006	.001 221	.902	.0144	22.4	156	-.000006	.001 198
795 000	500 000	.902	.0162	24.5	151	-.000007	.001 236	.902	.0158	24.5	154	-.000007	.001 210	.902	.0156	24.5	157	-.000006	.001 189
715 500	450 000	.902	.0179	27.3	153	-.000008	.001 225	.902	.0175	27.3	156	-.000007	.001 200	.902	.0172	27.3	158	-.000007	.001 178
636 000	400 000	.902	.0199	30.6	154	-.000008	.001 212	.902	.0195	30.6	157	-.000008	.001 189	.902	.0191	30.6	160	-.000008	.001 168
556 500	350 000	.902	.0223	34.5	155	-.000009	.001 208	.902	.0219	34.5	158	-.000009	.001 183	.902	.0215	34.5	161	-.000009	.001 161
477 000	300 000	.902	.0257	40.3	157	-.000011	.001 193	.902	.0252	40.3	160	-.000010	.001 168	.902	.0248	40.3	163	-.000010	.001 149
397 500	250 000	.902	.0303	48.3	159	-.000012	.001 174	.902	.0297	48.3	163	-.000012	.001 151	.902	.0292	48.3	166	-.000012	.001 132
336 400	0 000	.902	.0354	57.1	162	-.000014	.001 159	.902	.0347	57.1	165	-.000014	.001 136	.902	.0342	57.1	168	-.000013	.001 117
226 800	000	.902	.0435	71.9	166	-.000017	.001 129	.902	.0427	71.9	170	-.000017	.001 108	.902	.0419	71.9	173	-.000016	.001 089
0 000	00	.891	.0565	94.7	187	-.000022	.001 107	.891	.0554	94.7	190	-.000021	.001 086	.892	.0544	94.7	193	-.000020	.001 067

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.901	.00828	12.5	151	-.000004	.001 240	.901	.00814	12.5	154	-.000003	.001 219	.901	.00804	12.5	156	-.000003	.001 204
1 510 500	950 000	.902	.00864	13.1	152	-.000004	.001 234	.902	.00851	13.1	154	-.000004	.001 215	.902	.00839	13.1	156	-.000004	.001 198
1 431 000	900 000	.902	.00906	13.8	152	-.000004	.001 227	.902	.00891	13.8	155	-.000004	.001 208	.902	.00879	13.8	157	-.000004	.001 191
1 351 500	850 000	.902	.00952	14.6	153	-.000004	.001 221	.902	.00939	14.6	155	-.000004	.001 204	.902	.00925	14.6	157	-.000004	.001 187
1 272 000	800 000	.902	.0101	15.5	154	-.000004	.001 217	.902	.00990	15.5	156	-.000004	.001 198	.902	.00976	15.5	158	-.000004	.001 180
1 192 500	750 000	.902	.0106	16.5	155	-.000004	.001 208	.902	.0105	16.5	157	-.000004	.001 191	.902	.0103	16.5	159	-.000004	.001 174
1 113 000	700 000	.902	.0113	17.6	155	-.000005	.001 202	.902	.0112	17.6	158	-.000005	.001 185	.902	.0110	17.6	160	-.000004	.001 168
1 033 500	650 000	.902	.0121	19.0	156	-.000005	.001 193	.902	.0119	19.0	159	-.000005	.001 176	.902	.0118	19.0	161	-.000005	.001 161
954 000	600 000	.902	.0130	20.5	157	-.000005	.001 187	.902	.0128	20.5	160	-.000005	.001 170	.902	.0126	20.5	162	-.000005	.001 153
874 500	550 000	.902	.0141	22.4	158	-.000006	.001 178	.902	.0139	22.4	161	-.000006	.001 161	.902	.0137	22.4	163	-.000005	.001 144
795 000	500 000	.902	.0153	24.5	160	-.000006	.001 168	.902	.0151	24.5	162	-.000006	.001 151	.902	.0149	24.5	164	-.000006	.001 136
715 500	450 000	.902	.0170	27.3	161	-.000007	.001 159	.902	.0167	27.3	163	-.000007	.001 142	.902	.0165	27.3	166	-.000006	.001 127
636 000	400 000	.902	.0188	30.6	163	-.000008	.001 149	.902	.0185	30.6	165	-.000007	.001 132	.902	.0183	30.6	167	-.000007	.001 117
556 500	350 000	.902	.0211	34.5	163	-.000008	.001 144	.902	.0208	34.5	166	-.000008	.001 127	.902	.0206	34.5	168	-.000008	.001 112
477 000	300 000	.902	.0244	40.3	166	-.000010	.001 129	.902	.0240	40.3	168	-.000009	.001 115	.902	.0237	40.3	170	-.000009	.001 100
397 500	250 000	.902	.0288	48.3	168	-.000011	.001 115	.902	.0284	48.3	170	-.000011	.001 098	.902	.0280	48.3	173	-.000011	.001 085
336 400	0 000	.902	.0336	57.1	171	-.000013	.001 100	.902	.0332	57.1	173	-.000013	.001 085	.902	.0327	57.1	175	-.000012	.001 070
266 800	000	.902	.0413	71.9	175	-.000015	.001 072	.901	.0408	71.9	177	-.000015	.001 059	.902	.0403	71.9	180	-.000015	.001 046
0 000	00	.892	.0537	94.7	195	-.000020	.001 052	.892	.0529	94.7	198	-.000019	.001 037	.892	.0524	94.7	200	-.000019	.001 027

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXXXI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

230 MILES—370.15 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

9 FEET—2.743 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.0104	13.5	148	-.000005	.001 426
950 000	.889	.0108	14.1	148	-.000005	.001 419
900 000	.889	.0113	14.8	149	-.000006	.001 413
850 000	.889	.0118	15.6	150	-.000006	.001 404
800 000	.889	.0124	16.5	151	-.000006	.001 397
750 000	.889	.0131	17.4	152	-.000006	.001 388
700 000	.889	.0138	18.6	152	-.000007	.001 379
650 000	.889	.0147	19.9	154	-.000007	.001 370
600 000	.889	.0157	21.4	155	-.000008	.001 359
550 000	.889	.0169	23.3	156	-.000008	.001 348
500 000	.889	.0184	25.5	157	-.000009	.001 337
450 000	.889	.0202	28.2	159	-.000009	.001 324
400 000	.889	.0224	31.6	161	-.000010	.001 311
350 000	.889	.0252	36.0	163	-.000011	.001 295
300 000	.889	.0289	41.9	165	-.000013	.001 277
250 000	.889	.0340	50.1	167	-.000015	.001 258
0 000	.888	.0395	59.1	171	-.000017	.001 238
000	.888	.0488	74.4	175	-.000021	.001 215
00	.888	.0604	93.7	179	-.000025	.001 193

11 FEET—3.353 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.0100	13.5	153	-.000005	.001 373
950 000	.889	.0104	14.1	154	-.000005	.001 366
900 000	.889	.0109	14.8	154	-.000005	.001 359
850 000	.889	.0114	15.6	155	-.000005	.001 353
800 000	.889	.0120	16.5	156	-.000006	.001 346
750 000	.889	.0126	17.4	157	-.000006	.001 337
700 000	.889	.0133	18.6	158	-.000006	.001 331
650 000	.889	.0142	19.9	159	-.000007	.001 322
600 000	.889	.0152	21.4	160	-.000007	.001 311
550 000	.889	.0164	23.3	161	-.000007	.001 302
500 000	.889	.0178	25.5	163	-.000008	.001 291
450 000	.889	.0195	28.2	164	-.000009	.001 280
400 000	.889	.0216	31.6	166	-.000010	.001 266
350 000	.889	.0243	36.0	168	-.000011	.001 251
300 000	.889	.0279	41.9	170	-.000012	.001 235
250 000	.889	.0330	50.1	173	-.000014	.001 218
0 000	.888	.0382	59.1	177	-.000016	.001 198
000	.888	.0472	74.4	180	-.000020	.001 176
00	.888	.0585	93.7	184	-.000024	.001 156

13 FEET—3.962 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00974	13.5	157	-.000005	.001 333
950 000	.889	.0101	14.1	158	-.000005	.001 326
900 000	.889	.0106	14.8	159	-.000005	.001 320
850 000	.889	.0111	15.6	160	-.000005	.001 313
800 000	.889	.0116	16.5	161	-.000005	.001 306
750 000	.889	.0122	17.4	161	-.000006	.001 300
700 000	.889	.0129	18.6	162	-.000006	.001 291
650 000	.889	.0138	19.9	163	-.000006	.001 282
600 000	.889	.0147	21.4	165	-.000007	.001 273
550 000	.889	.0159	23.3	166	-.000007	.001 264
500 000	.889	.0173	25.5	167	-.000008	.001 255
450 000	.889	.0189	28.2	168	-.000008	.001 244
400 000	.889	.0210	31.6	171	-.000009	.001 231
350 000	.889	.0237	36.0	173	-.000010	.001 218
300 000	.889	.0272	41.9	175	-.000012	.001 202
250 000	.889	.0320	50.1	177	-.000013	.001 184
0 000	.888	.0372	59.1	181	-.000015	.001 167
000	.888	.0461	74.4	185	-.000019	.001 147
00	.888	.0570	93.7	189	-.000023	.001 127

15 FEET—4.572 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00950	13.5	161	-.000004	.001 300
950 000	.889	.00987	14.1	162	-.000004	.001 293
900 000	.889	.0103	14.8	163	-.000005	.001 286
850 000	.889	.0108	15.6	163	-.000005	.001 282
800 000	.889	.0113	16.5	164	-.000005	.001 275
750 000	.889	.0119	17.4	165	-.000005	.001 266
700 000	.889	.0126	18.6	166	-.000006	.001 260
650 000	.889	.0135	19.9	167	-.000006	.001 253
600 000	.889	.0144	21.4	168	-.000006	.001 244
550 000	.889	.0155	23.3	170	-.000007	.001 235
500 000	.889	.0168	25.5	171	-.000007	.001 224
450 000	.889	.0185	28.2	172	-.000008	.001 215
400 000	.889	.0205	31.6	174	-.000009	.001 202
350 000	.889	.0231	36.0	176	-.000010	.001 189
300 000	.889	.0266	41.9	178	-.000011	.001 17[illegible]
250 000	.889	.0313	50.1	181	-.000013	.001 15[illegible]
0 000	.888	.0364	59.1	185	-.000015	.001 142
000	.888	.0451	74.4	189	-.000018	.001 122
00	.888	.0558	93.7	192	-.000022	.001 103

17 FEET—5.182 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00929	13.5	165	-.000004	.001 271
950 000	.889	.00967	14.1	165	-.000004	.001 266
900 000	.889	.0101	14.8	166	-.000004	.001 260
850 000	.889	.0105	15.6	167	-.000005	.001 253
800 000	.889	.0111	16.5	168	-.000005	.001 249
750 000	.889	.0117	17.4	169	-.000005	.001 242
700 000	.889	.0124	18.6	169	-.000005	.001 233
650 000	.889	.0132	19.9	171	-.000006	.001 227
600 000	.889	.0141	21.4	172	-.000006	.001 218
550 000	.889	.0152	23.3	173	-.000006	.001 209
500 000	.889	.0165	25.5	174	-.000007	.001 200
450 000	.889	.0181	28.2	176	-.000008	.001 191
400 000	.889	.0201	31.6	178	-.000008	.001 178
350 000	.889	.0227	36.0	180	-.000009	.001 167
300 000	.889	.0260	41.9	182	-.000011	.001 151
250 000	.889	.0307	50.1	185	-.000012	.001 136
0 000	.889	.0358	59.1	188	-.000014	.001 120
000	.889	.0442	74.4	192	-.000017	.001 100
00	.888	.0548	93.7	196	-.000021	.001 083

19 FEET—5.791 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00913	13.5	168	-.000004	.001 249
950 000	.889	.00949	14.1	168	-.000004	.001 242
900 000	.889	.00991	14.8	169	-.000004	.001 238
850 000	.889	.0104	15.6	170	-.000004	.001 231
800 000	.889	.0109	16.5	171	-.000005	.001 224
750 000	.889	.0115	17.4	172	-.000005	.001 218
700 000	.889	.0121	18.6	173	-.000005	.001 211
650 000	.889	.0129	19.9	173	-.000005	.001 204
600 000	.889	.0138	21.4	175	-.000006	.001 196
550 000	.889	.0149	23.3	176	-.000006	.001 189
500 000	.889	.0162	25.5	177	-.000007	.001 180
450 000	.889	.0178	28.2	179	-.000007	.001 169
400 000	.889	.0198	31.6	181	-.000008	.001 158
350 000	.889	.0223	36.0	183	-.000009	.001 147
300 000	.889	.0256	41.9	185	-.000010	.001 134
250 000	.889	.0303	50.1	187	-.000012	.001 118
0 000	.889	.0352	59.1	191	-.000014	.001 103
000	.889	.0435	74.4	195	-.000017	.001 083
00	.889	.053[illegible]	93.7	199	-.000020	.001 065

21 FEET—6.401 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00896	13.5	170	-.000004	.001 227
950 000	.889	.00933	14.1	171	-.000004	.001 222
900 000	.889	.00975	14.8	172	-.000004	.001 218
850 000	.889	.0102	15.6	173	-.000004	.001 211
800 000	.889	.0107	16.5	173	-.000005	.001 204
750 000	.889	.0113	17.4	174	-.000005	.001 198
700 000	.889	.0119	18.6	175	-.000005	.001 191
650 000	.890	.0127	19.9	176	-.000005	.001 184
600 000	.889	.0136	21.4	177	-.000006	.001 178
550 000	.889	.0147	23.3	179	-.000006	.001 169
500 000	.889	.0160	25.5	180	-.000007	.001 160
450 000	.889	.0175	28.2	182	-.000007	.001 151
400 000	.889	.0195	31.6	184	-.000008	.001 140
350 000	.889	.0219	36.0	185	-.000009	.001 129
300 000	.889	.0252	41.9	187	-.000010	.001 116
250 000	.889	.0298	50.1	190	-.000012	.001 100
0 000	.889	.0346	59.1	194	-.000013	.001 085
000	.889	.0429	74.4	198	-.000016	.001 067
00	.889	.0531	93.7	201	-.000020	.001 049

23 FEET—7.010 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00883	13.5	173	-.000004	.001 209
950 000	.889	.00920	14.1	173	-.000004	.001 204
900 000	.889	.00960	14.8	174	-.000004	.001 200
850 000	.889	.0100	15.6	175	-.000004	.001 193
800 000	.889	.0105	16.5	176	-.000004	.001 187
750 000	.889	.0111	17.4	177	-.000005	.001 182
700 000	.889	.0118	18.6	178	-.000005	.001 176
650 000	.889	.0126	19.9	179	-.000005	.001 169
600 000	.889	.0134	21.4	180	-.000005	.001 160
550 000	.889	.0145	23.3	181	-.000006	.001 153
500 000	.889	.0157	25.5	182	-.000006	.001 145
450 000	.889	.0173	28.2	184	-.000007	.001 136
400 000	.889	.0192	31.6	186	-.000008	.001 125
350 000	.889	.0216	36.0	188	-.000008	.001 114
300 000	.889	.0249	41.9	190	-.000010	.001 100
250 000	.889	.0294	50.1	192	-.000011	.001 087
0 000	.889	.0342	59.1	196	-.000013	.001 072
000	.889	.0423	74.4	200	-.000016	.001 054
00	.889	.0525	93.7	204	-.000019	.001 036

25 FEET—7.620 METERS

CIRCULAR MILS OR A W G (B & S)	A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.889	.00872	13.5	175	-.000004	.001 193
950 000	.889	.00908	14.1	176	-.000004	.001 189
900 000	.889	.00946	14.8	177	-.000004	.001 182
850 000	.889	.00992	15.6	177	-.000004	.001 178
800 000	.889	.0104	16.5	178	-.000004	.001 171
750 000	.889	.0110	17.4	179	-.000005	.001 167
700 000	.889	.0116	18.6	180	-.000005	.001 160
650 000	.889	.0124	19.9	181	-.000005	.001 153
600 000	.889	.0133	21.4	182	-.000005	.001 147
550 000	.889	.0143	23.3	183	-.000006	.001 138
500 000	.889	.0155	25.5	185	-.000006	.001 129
450 000	.889	.0170	28.2	186	-.000007	.001 120
400 000	.889	.0190	31.6	188	-.000007	.001 111
350 000	.889	.0214	36.0	190	-.000008	.001 100
300 000	.889	.0246	41.9	192	-.000009	.001 087
250 000	.889	.0291	50.1	195	-.000011	.001 074
0 000	.889	.0338	59.1	199	-.000013	.001 058
000	.889	.0418	74.4	202	-.000015	.001 041
00	.889	.0519	93.7	206	-.000019	.001 025

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI. l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXXII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

230 MILES—370.15 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.892	.0106	13.0	135	-.000 006	.001 512	.892	.0102	13.0	140	-.000 005	.001 454	.892	.00982	13.0	145	-.000 005	.001 408
1 510 500	950 000	.892	.0110	13.6	135	-.000 006	.001 505	.892	.0106	13.6	141	-.000 005	.001 445	.892	.0103	13.6	145	-.000 005	.001 401
1 431 000	900 000	.893	.0115	14.3	136	-.000 006	.001 496	.893	.0111	14.3	142	-.000 006	.001 439	.893	.0108	14.3	146	-.000 005	.001 394
1 351 500	850 000	.893	.0121	15.1	137	-.000 006	.001 488	.893	.0117	15.1	142	-.000 006	.001 430	.893	.0113	15.1	147	-.000 005	.001 386
1 272 000	800 000	.893	.0128	16.1	138	-.000 007	.001 479	.893	.0123	16.1	143	-.000 006	.001 423	.893	.0119	16.1	148	-.000 006	.001 379
1 192 500	750 000	.893	.0135	17.1	138	-.000 007	.001 470	.893	.0130	17.1	144	-.000 006	.001 414	.893	.0126	17.1	148	-.000 006	.001 370
1 113 000	700 000	.893	.0144	18.3	139	-.000 007	.001 461	.893	.0138	18.3	145	-.000 007	.001 406	.893	.0134	18.3	149	-.000 006	.001 363
1 033 500	650 000	.893	.0154	19.7	140	-.000 008	.001 450	.893	.0148	19.7	146	-.000 007	.001 394	.893	.0143	19.7	150	-.000 007	.001 352
954 000	600 000	.893	.0165	21.3	141	-.000 008	.001 439	.893	.0159	21.3	147	-.000 008	.001 386	.893	.0154	21.3	151	-.000 007	.001 344
874 500	550 000	.893	.0179	23.3	142	-.000 009	.001 426	.893	.0172	23.3	148	-.000 008	.001 372	.893	.0167	23.3	152	-.000 008	.001 332
795 000	500 000	.893	.0193	25.4	144	-.000 010	.001 414	.893	.0186	25.4	149	-.000 009	.001 361	.893	.0181	25.4	154	-.000 008	.001 321
715 500	450 000	.893	.0214	28.4	145	-.000 010	.001 399	.893	.0206	28.4	151	-.000 010	.001 350	.893	.0200	28.4	155	-.000 009	.001 308
636 000	400 000	.893	.0237	31.8	147	-.000 012	.001 383	.893	.0229	31.8	152	-.000 011	.001 335	.893	.0222	31.8	157	-.000 010	.001 295
556 500	350 000	.893	.0266	35.9	148	-.000 013	.001 379	.893	.0256	35.9	153	-.000 012	.001 328	.893	.0249	35.9	157	-.000 011	.001 290
477 000	300 000	.893	.0306	41.8	150	-.000 015	.001 359	.893	.0295	41.8	155	-.000 014	.001 310	.893	.0287	41.8	160	-.000 013	.001 275
397 500	250 000	.893	.0361	50.2	153	-.000 017	.001 337	.893	.0349	50.2	158	-.000 016	.001 290	.893	.0339	50.2	162	-.000 015	.001 255
336 400	0 000	.892	.0421	59.3	155	-.000 019	.001 317	.892	.0407	59.3	161	-.000 018	.001 273	.893	.0395	59.3	165	-.000 017	.001 237
266 800	000	.892	.0516	74.7	160	-.000 023	.001 281	.892	.0498	74.7	165	-.000 022	.001 237	.892	.0485	74.7	170	-.000 021	.001 206
0 000	00	.880	.0668	98.3	181	-.000 030	.001 252	.881	.0645	98.3	187	-.000 028	.001 210	.881	.0629	98.3	191	-.000 026	.001 179

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.892	.00956	13.0	149	-.000 004	.001 370	.893	.00934	13.0	152	-.000 004	.001 339	.892	.00917	13.0	155	-.000 004	.001 315
1 510 500	950 000	.892	.00998	13.6	149	-.000 005	.001 363	.892	.00977	13.6	153	-.000 004	.001 335	.893	.00958	13.6	155	-.000 004	.001 308
1 431 000	900 000	.893	.0105	14.3	150	-.000 005	.001 357	.893	.0102	14.3	153	-.000 005	.001 328	.893	.0100	14.3	156	-.000 005	.001 301
1 351 500	850 000	.893	.0110	15.1	151	-.000 005	.001 350	.893	.0108	15.1	154	-.000 005	.001 321	.893	.0106	15.1	157	-.000 005	.001 295
1 272 000	800 000	.893	.0116	16.1	151	-.000 005	.001 344	.893	.0114	16.1	155	-.000 005	.001 315	.893	.0111	16.1	158	-.000 005	.001 288
1 192 500	750 000	.893	.0123	17.1	152	-.000 006	.001 335	.893	.0120	17.1	156	-.000 006	.001 306	.893	.0118	17.1	158	-.000 005	.001 281
1 113 000	700 000	.893	.0131	18.3	153	-.000 006	.001 328	.893	.0128	18.3	156	-.000 006	.001 299	.893	.0126	18.3	159	-.000 006	.001 275
1 033 500	650 000	.893	.0140	19.7	154	-.000 006	.001 319	.893	.0137	19.7	157	-.000 006	.001 290	.893	.0134	19.7	160	-.000 006	.001 266
954 000	600 000	.893	.0150	21.3	155	-.000 007	.001 310	.893	.0147	21.3	158	-.000 007	.001 281	.893	.0144	21.3	161	-.000 006	.001 257
874 500	550 000	.893	.0163	23.3	156	-.000 007	.001 299	.893	.0159	23.3	160	-.000 007	.001 273	.893	.0156	23.3	162	-.000 007	.001 248
795 000	500 000	.893	.0176	25.4	157	-.000 008	.001 288	.893	.0173	25.4	161	-.000 008	.001 261	.893	.0170	25.4	164	-.000 007	.001 239
715 500	450 000	.893	.0195	28.4	159	-.000 009	.001 277	.893	.0191	28.4	162	-.000 008	.001 250	.893	.0188	28.4	165	-.000 008	.001 228
636 000	400 000	.893	.0216	31.8	161	-.000 010	.001 264	.893	.0212	31.8	164	-.000 009	.001 239	.893	.0208	31.8	167	-.000 009	.001 217
556 500	350 000	.893	.0243	35.9	161	-.000 011	.001 259	.893	.0238	35.9	165	-.000 010	.001 233	.893	.0234	35.9	168	-.000 010	.001 210
477 000	300 000	.893	.0280	41.8	163	-.000 012	.001 244	.893	.0274	41.8	167	-.000 012	.001 217	.893	.0270	41.8	170	-.000 011	.001 197
397 500	250 000	.893	.0331	50.2	166	-.000 014	.001 224	.893	.0324	50.2	170	-.000 014	.001 199	.893	.0319	50.2	173	-.000 013	.001 179
336 400	0 000	.893	.0386	59.3	169	-.000 016	.001 208	.893	.0378	59.3	172	-.000 016	.001 184	.893	.0372	59.3	175	-.000 015	.001 164
266 800	000	.892	.0474	74.7	174	-.000 020	.001 177	.892	.0465	74.7	177	-.000 019	.001 155	.892	.0457	74.7	180	-.000 018	.001 135
0 000	00	.881	.0615	98.3	195	-.000 025	.001 153	.881	.0604	98.4	198	-.000 024	.001 131	.882	.0593	98.4	201	-.000 023	.001 111

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		B	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.892	.00902	13.0	158	-.000 004	.001 293	.892	.00886	13.0	160	-.000 004	.001 270	.892	.00876	13.0	162	-.000 004	.001 255
1 510 500	950 000	.893	.00942	13.6	158	-.000 004	.001 286	.893	.00927	13.6	161	-.000 004	.001 266	.893	.00914	13.6	163	-.000 004	.001 248
1 431 000	900 000	.893	.00987	14.3	159	-.000 004	.001 279	.893	.00971	14.3	161	-.000 004	.001 259	.893	.00958	14.3	163	-.000 004	.001 242
1 351 500	850 000	.893	.0104	15.1	160	-.000 005	.001 273	.893	.0102	15.1	162	-.000 005	.001 255	.893	.0101	15.1	164	-.000 004	.001 237
1 272 000	800 000	.893	.0110	16.1	160	-.000 005	.001 268	.893	.0108	16.1	163	-.000 005	.001 248	.893	.0106	16.1	165	-.000 005	.001 230
1 192 500	750 000	.893	.0116	17.1	161	-.000 005	.001 259	.893	.0114	17.1	164	-.000 005	.001 242	.893	.0113	17.1	166	-.000 005	.001 224
1 113 000	700 000	.893	.0123	18.3	162	-.000 005	.001 253	.893	.0122	18.3	164	-.000 005	.001 235	.893	.0120	18.3	167	-.000 005	.001 217
1 033 500	650 000	.893	.0132	19.7	163	-.000 006	.001 244	.893	.0130	19.7	165	-.000 006	.001 226	.893	.0128	19.7	168	-.000 005	.001 210
954 000	600 000	.893	.0142	21.3	164	-.000 006	.001 237	.893	.0140	21.3	167	-.000 006	.001 219	.893	.0138	21.3	169	-.000 006	.001 202
874 500	550 000	.893	.0154	23.3	165	-.000 007	.001 228	.893	.0152	23.3	168	-.000 006	.001 210	.893	.0149	23.3	170	-.000 006	.001 193
795 000	500 000	.893	.0167	25.4	167	-.000 007	.001 217	.893	.0164	25.4	169	-.000 007	.001 199	.893	.0162	25.4	171	-.000 007	.001 184
715 500	450 000	.893	.0185	28.4	168	-.000 008	.001 208	.893	.0182	28.4	170	-.000 008	.001 191	.893	.0180	28.4	173	-.000 007	.001 175
636 000	400 000	.893	.0205	31.8	169	-.000 009	.001 197	.893	.0202	31.8	172	-.000 008	.001 179	.893	.0199	31.8	174	-.000 008	.001 164
556 500	350 000	.893	.0230	35.9	170	-.000 010	.001 193	.893	.0227	35.9	173	-.000 009	.001 175	.893	.0224	35.9	175	-.000 009	.001 159
477 000	300 000	.893	.0265	41.8	172	-.000 011	.001 177	.893	.0262	41.8	175	-.000 011	.001 162	.893	.0258	41.8	177	-.000 010	.001 146
397 500	250 000	.893	.0314	50.2	175	-.000 013	.001 162	.893	.0309	50.2	178	-.000 012	.001 144	.893	.0306	50.2	180	-.000 012	.001 131
336 400	0 000	.893	.0366	59.3	178	-.000 015	.001 146	.893	.0361	59.3	180	-.000 014	.001 131	.893	.0356	59.3	183	-.000 014	.001 115
266 800	000	.893	.0450	74.7	183	-.000 018	.001 117	.892	.0444	74.7	185	-.000 017	.001 104	.892	.0439	74.7	187	-.000 017	.001 091
0 000	00	.882	.0585	98.4	204	-.000 023	.001 096	.882	.0576	98.4	206	-.000 022	.001 080	.882	.0571	98.4	208	-.000 022	.001 069

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXXIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

240 MILES—386.24 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.879	.011 3	14.0	153	−.000 006	.001 483	.879	.010 9	14.0	159	−.000 005	.001 428	.879	.010 6	14.0	164	−.000 005	.001 386
950 000	.879	.011 8	14.7	154	−.000 006	.001 476	.879	.011 3	14.7	160	−.000 006	.001 421	.879	.011 0	14.7	164	−.000 005	.001 379
900 000	.879	.012 3	15.4	155	−.000 006	.001 469	.879	.011 8	15.4	161	−.000 006	.001 414	.879	.011 5	15.4	165	−.000 006	.001 373
850 000	.879	.012 8	16.2	156	−.000 007	.001 460	.879	.012 3	16.2	162	−.000 006	.001 407	.879	.012 0	16.2	166	−.000 006	.001 366
800 000	.879	.013 5	17.1	157	−.000 007	.001 453	.879	.013 0	17.1	162	−.000 006	.001 400	.879	.012 6	17.1	167	−.000 006	.001 359
750 000	.879	.014 2	18.1	158	−.000 007	.001 444	.879	.013 7	18.1	163	−.000 007	.001 391	.879	.013 3	18.1	168	−.000 006	.001 352
700 000	.879	.015 0	19.3	159	−.000 008	.001 435	.879	.014 5	19.3	164	−.000 007	.001 384	.879	.014 0	19.3	169	−.000 007	.001 343
650 000	.879	.016 0	20.6	160	−.000 008	.001 426	.879	.015 4	20.6	165	−.000 007	.001 375	.879	.014 9	20.6	170	−.000 007	.001 333
600 000	.879	.017 1	22.2	161	−.000 009	.001 414	.879	.016 5	22.2	167	−.000 008	.001 363	.879	.016 0	22.2	171	−.000 007	.001 324
550 000	.879	.018 4	24.1	162	−.000 009	.001 403	.879	.017 7	24.1	168	−.000 008	.001 354	.879	.017 2	24.1	172	−.000 008	.001 315
500 000	.879	.020 0	26.4	163	−.000 010	.001 391	.879	.019 3	26.4	169	−.000 009	.001 343	.879	.018 7	26.4	174	−.000 009	.001 306
450 000	.879	.021 9	29.2	165	−.000 011	.001 377	.879	.021 1	29.2	171	−.000 010	.001 331	.879	.020 5	29.2	175	−.000 009	.001 294
400 000	.879	.024 2	32.8	167	−.000 012	.001 363	.879	.023 4	32.8	173	−.000 011	.001 317	.879	.022 8	32.8	177	−.000 010	.001 280
350 000	.879	.027 3	37.3	169	−.000 013	.001 347	.879	.026 4	37.3	175	−.000 012	.001 301	.879	.025 7	37.3	180	−.000 011	.001 267
300 000	.879	.031 3	43.4	171	−.000 015	.001 329	.879	.030 3	43.4	177	−.000 014	.001 285	.879	.029 5	43.4	182	−.000 013	.001 251
250 000	.879	.036 9	52.0	174	−.000 017	.001 308	.879	.035 7	52.0	180	−.000 016	.001 267	.879	.034 7	52.0	184	−.000 015	.001 232
0 000	.878	.042 8	61.3	178	−.000 020	.001 287	.878	.041 5	61.3	184	−.000 018	.001 246	.879	.040 4	61.3	189	−.000 017	.001 214
000	.878	.053 0	77.1	182	−.000 024	.001 264	.878	.051 2	77.1	188	−.000 022	.001 223	.878	.050 0	77.1	192	−.000 021	.001 193
00	.878	.065 5	97.2	186	−.000 029	.001 241	.878	.063 4	97.2	192	−.000 027	.001 202	.878	.061 9	97.2	196	−.000 026	.001 172

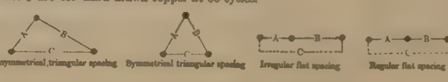
CIRCULAR MILS OR A W G (B & S)	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.879	.010 3	14.0	168	−.000 005	.001 352	.879	.010 1	14.0	171	−.000 005	.001 322	.880	.009 90	14.0	174	−.000 005	.001 299
950 000	.879	.010 7	14.7	169	−.000 005	.001 345	.880	.010 5	14.7	172	−.000 005	.001 317	.880	.010 3	14.7	175	−.000 005	.001 292
900 000	.879	.011 2	15.4	169	−.000 005	.001 338	.880	.010 9	15.4	173	−.000 005	.001 310	.880	.010 7	15.4	176	−.000 005	.001 287
850 000	.879	.011 7	16.2	170	−.000 006	.001 333	.880	.011 4	16.2	173	−.000 005	.001 303	.880	.011 2	16.2	177	−.000 005	.001 280
800 000	.879	.012 3	17.1	171	−.000 006	.001 327	.880	.012 0	17.1	174	−.000 006	.001 299	.880	.011 8	17.1	178	−.000 005	.001 274
750 000	.879	.012 9	18.1	172	−.000 006	.001 317	.880	.012 7	18.1	175	−.000 006	.001 292	.880	.012 4	18.1	179	−.000 006	.001 267
700 000	.880	.013 7	19.3	173	−.000 006	.001 310	.880	.013 4	19.3	176	−.000 006	.001 283	.880	.013 2	19.3	179	−.000 006	.001 260
650 000	.880	.014 6	20.6	174	−.000 007	.001 303	.880	.014 3	20.6	177	−.000 006	.001 276	.880	.014 0	20.6	180	−.000 006	.001 253
600 000	.880	.015 6	22.2	175	−.000 007	.001 294	.880	.015 3	22.2	179	−.000 007	.001 267	.880	.015 0	22.2	182	−.000 007	.001 244
550 000	.879	.016 8	24.1	177	−.000 008	.001 285	.880	.016 5	24.1	180	−.000 007	.001 257	.880	.016 2	24.1	183	−.000 007	.001 237
500 000	.879	.018 3	26.4	178	−.000 008	.001 274	.880	.017 9	26.4	181	−.000 008	.001 248	.880	.017 6	26.4	184	−.000 008	.001 227
450 000	.879	.020 1	29.2	179	−.000 009	.001 264	.880	.019 7	29.2	183	−.000 009	.001 239	.880	.019 3	29.2	186	−.000 008	.001 216
400 000	.879	.022 2	32.8	182	−.000 010	.001 251	.880	.021 8	32.8	185	−.000 009	.001 225	.880	.021 4	32.8	188	−.000 009	.001 204
350 000	.879	.025 0	37.3	183	−.000 011	.001 237	.880	.024 6	37.3	187	−.000 011	.001 214	.880	.024 2	37.3	190	−.000 010	.001 193
300 000	.879	.028 8	43.4	186	−.000 012	.001 223	.880	.028 2	43.4	189	−.000 012	.001 198	.880	.027 8	43.4	192	−.000 012	.001 179
250 000	.879	.034 0	52.0	188	−.000 014	.001 204	.880	.033 3	52.0	192	−.000 014	.001 181	.880	.032 8	52.0	195	−.000 014	.001 163
0 000	.879	.039 5	61.3	192	−.000 017	.001 188	.879	.038 8	61.3	196	−.000 016	.001 165	.879	.038 1	61.3	199	−.000 015	.001 147
000	.879	.048 9	77.1	196	−.000 020	.001 168	.879	.047 9	77.1	200	−.000 019	.001 145	.879	.047 2	77.1	203	−.000 019	.001 126
00	.879	.060 5	97.2	200	−.000 025	.001 147	.879	.059 4	97.2	204	−.000 024	.001 126	.879	.058 5	97.2	207	−.000 023	.001 108

CIRCULAR MILS OR A W G (B & S)	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.880	.009 72	14.0	177	−.000 004	.001 276	.880	.009 58	14.0	180	−.000 004	.001 257	.880	.009 46	14.0	182	−.000 004	.001 241
950 000	.880	.010 1	14.7	178	−.000 005	.001 271	.880	.009 97	14.7	180	−.000 004	.001 253	.880	.009 84	14.7	183	−.000 004	.001 237
900 000	.880	.010 6	15.4	179	−.000 005	.001 267	.880	.010 4	15.4	181	−.000 005	.001 248	.880	.010 3	15.4	184	−.000 004	.001 230
850 000	.880	.011 1	16.2	179	−.000 005	.001 260	.880	.010 9	16.2	182	−.000 005	.001 241	.880	.010 8	16.2	184	−.000 005	.001 225
800 000	.880	.011 6	17.1	180	−.000 005	.001 253	.880	.011 4	17.1	183	−.000 005	.001 234	.880	.011 3	17.1	185	−.000 005	.001 218
750 000	.880	.012 2	18.1	181	−.000 005	.001 246	.880	.012 1	18.1	184	−.000 005	.001 230	.880	.011 9	18.1	186	−.000 005	.001 214
700 000	.880	.013 0	19.3	182	−.000 006	.001 239	.880	.012 8	19.3	185	−.000 006	.001 223	.880	.012 6	19.3	187	−.000 005	.001 207
650 000	.880	.013 8	20.6	183	−.000 006	.001 232	.880	.013 6	20.6	186	−.000 006	.001 216	.880	.013 4	20.6	188	−.000 006	.001 200
600 000	.880	.014 8	22.2	185	−.000 006	.001 225	.880	.014 6	22.2	187	−.000 006	.001 207	.880	.014 4	22.2	189	−.000 006	.001 193
550 000	.880	.015 9	24.1	186	−.000 007	.001 216	.880	.015 7	24.1	188	−.000 007	.001 200	.880	.015 5	24.1	191	−.000 006	.001 184
500 000	.880	.017 3	26.4	187	−.000 007	.001 207	.880	.017 1	26.4	190	−.000 007	.001 191	.880	.016 8	26.4	192	−.000 007	.001 175
450 000	.880	.019 0	29.2	189	−.000 008	.001 198	.880	.018 7	29.2	191	−.000 008	.001 181	.880	.018 5	29.2	194	−.000 008	.001 165
400 000	.880	.021 1	32.8	191	−.000 009	.001 186	.880	.020 8	32.8	193	−.000 009	.001 170	.880	.020 6	32.8	196	−.000 008	.001 156
350 000	.880	.023 8	37.3	193	−.000 010	.001 175	.880	.023 5	37.3	195	−.000 010	.001 158	.880	.023 2	37.3	198	−.000 009	.001 145
300 000	.880	.027 3	43.4	195	−.000 011	.001 161	.880	.027 0	43.4	198	−.000 011	.001 145	.880	.026 6	43.4	200	−.000 011	.001 131
250 000	.880	.032 3	52.0	198	−.000 013	.001 145	.880	.031 9	52.0	200	−.000 013	.001 131	.880	.031 5	52.0	203	−.000 012	.001 117
0 000	.879	.037 5	61.3	202	−.000 015	.001 128	.879	.037 1	61.3	204	−.000 015	.001 115	.879	.036 6	61.3	207	−.000 014	.001 101
000	.879	.046 5	77.1	206	−.000 018	.001 110	.879	.045 9	77.1	208	−.000 018	.001 096	.879	.045 3	77.1	210	−.000 017	.001 082
00	.879	.057 6	97.2	210	−.000 022	.001 092	.879	.056 9	97.2	212	−.000 022	.001 078	.879	.056 3	97.2	214	−.000 021	.001 066

$A = \cosh\theta = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40,320}+\right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5,040}+\frac{Z^4Y^4}{362,880}+\right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5,040}+\frac{Z^4Y^4}{362,880}+\right)$

in which Z is the total impedance $(rl+jxl)$ in ohms and Y is the total admittance $(o+jbl\times10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D=\sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE LXXXIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

240 MILES—386.24 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.883	.0115	13.4	140	-.000006	.001 572	.883	.0110	13.4	146	-.000006	.001 512	.883	.0107	13.4	151	-.000006	.001 464
1 510 500	950 000	.883	.0120	14.1	141	-.000007	.001 565	.883	.0115	14.1	147	-.000006	.001 503	.883	.0111	14.1	151	-.000006	.001 457
1 431 000	900 000	.883	.0125	14.8	141	-.000007	.001 556	.883	.0120	14.8	147	-.000006	.001 496	.883	.0117	14.8	152	-.000006	.001 450
1 351 500	850 000	.883	.0132	15.7	142	-.000007	.001 547	.883	.0126	15.7	148	-.000007	.001 487	.883	.0123	15.7	153	-.000006	.001 441
1 272 000	800 000	.883	.0139	16.6	143	-.000008	.001 537	.883	.0134	16.6	149	-.000007	.001 480	.883	.0129	16.6	153	-.000007	.001 434
1 192 500	750 000	.883	.0147	17.7	144	-.000008	.001 528	.883	.0141	17.7	150	-.000007	.001 471	.883	.0137	17.7	154	-.000007	.001 424
1 113 000	700 000	.883	.0156	19.0	145	-.000008	.001 519	.883	.0150	19.0	150	-.000008	.001 461	.883	.0146	19.0	155	-.000007	.001 418
1 033 500	650 000	.883	.0167	20.4	146	-.000009	.001 507	.883	.0160	20.4	151	-.000008	.001 450	.884	.0156	20.4	156	-.000008	.001 406
954 000	600 000	.883	.0179	22.1	147	-.000009	.001 496	.883	.0172	22.1	153	-.000009	.001 441	.883	.0167	22.1	157	-.000008	.001 397
874 500	550 000	.883	.0194	24.1	148	-.000010	.001 482	.883	.0187	24.1	154	-.000009	.001 427	.883	.0181	24.1	158	-.000009	.001 385
795 000	500 000	.883	.0210	26.3	149	-.000011	.001 471	.883	.0202	26.3	155	-.000010	.001 415	.883	.0196	26.3	160	-.000010	.001 374
715 500	450 000	.883	.0232	29.4	151	-.000012	.001 454	.883	.0224	29.4	157	-.000011	.001 404	.884	.0217	29.4	161	-.000010	.001 360
636 000	400 000	.883	.0257	33.0	153	-.000013	.001 438	.883	.0248	33.0	158	-.000012	.001 388	.884	.0241	33.0	163	-.000011	.001 346
556 500	350 000	.883	.0289	37.2	154	-.000015	.001 434	.883	.0278	37.2	159	-.000014	.001 381	.884	.0270	37.2	164	-.000013	.001 342
477 000	300 000	.883	.0332	43.4	156	-.000017	.001 413	.883	.0320	43.4	161	-.000015	.001 362	.883	.0312	43.4	166	-.000015	.001 325
397 500	250 000	.883	.0392	52.0	159	-.000019	.001 390	.883	.0378	52.0	164	-.000018	.001 342	.883	.0368	52.0	169	-.000017	.001 305
336 400	0 000	.883	.0457	61.5	161	-.000022	.001 369	.883	.0441	61.5	167	-.000021	.001 323	.883	.0429	61.5	172	-.000019	.001 286
266 800	000	.883	.0559	77.4	166	-.000026	.001 332	.883	.0540	77.4	172	-.000025	.001 286	.883	.0527	77.4	177	-.000023	.001 254
0 000	00	.869	.0724	102.	189	-.000033	.001 302	.870	.0700	102.	194	-.000031	.001 258	.871	.0682	102.	199	-.000030	.001 226

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.883	.0104	13.4	155	-.000005	.001 424	.883	.0101	13.4	158	-.000005	.001 392	883	.00995	13 4	161	-.000005	.001 367
1 510 500	950 000	.883	.0108	14.1	155	-.000005	.001 418	.883	.0106	14.1	159	-.000005	.001 388	.883	.0104	14.1	162	-.000005	.001 360
1 431 000	900 000	.883	.0114	14.8	156	-.000006	.001 411	.883	.0111	14.8	159	-.000005	.001 381	.883	.0109	14.8	162	-.000005	.001 353
1 351 500	850 000	.883	.0119	15.7	157	-.000006	.001 404	.883	.0117	15.7	160	-.000006	.001 374	.883	.0115	15.7	163	-.000005	.001 346
1 272 000	800 000	.883	.0126	16.6	157	-.000006	.001 397	.883	.0123	16.6	161	-.000006	.001 367	.883	.0121	16.6	164	-.000006	.001 339
1 192 500	750 000	.883	.0133	17.7	158	-.000007	.001 388	.883	.0131	17.7	162	-.000006	.001 358	.883	.0128	17.7	165	-.000006	.001 332
1 113 000	700 000	.883	.0142	19.0	159	-.000007	.001 381	.883	.0139	19.0	163	-.000007	.001 351	.883	.0136	19.0	166	-.000006	.001 325
1 033 500	650 000	.884	.0152	20.4	160	-.000007	.001 371	.884	.0148	20.4	164	-.000007	.001 342	.884	.0146	20.4	167	-.000007	.001 316
954 000	600 000	.883	.0163	22.1	161	-.000008	.001 362	.883	.0159	22.1	165	-.000007	.001 332	.884	.0156	22.1	168	-.000007	.001 307
874 500	550 000	.884	.0177	24.1	162	-.000008	.001 351	.884	.0173	24.1	166	-.000008	.001 323	.884	.0170	24.1	169	-.000008	.001 298
795 000	500 000	.884	.0191	26.3	164	-.000009	.001 339	.884	.0187	26.3	167	-.000009	.001 312	.884	.0184	26.3	170	-.000008	.001 288
715 500	450 000	.884	.0212	29.4	165	-.000010	.001 328	.884	.0207	29.4	169	-.000010	.001 300	.884	.0204	29.4	172	-.000009	.001 277
636 000	400 000	.884	.0235	33.0	167	-.000011	.001 314	.884	.0230	33.0	170	-.000010	.001 288	.884	.0226	33.0	173	-.000010	.001 265
556 500	350 000	.884	.0264	37.2	168	-.000012	.001 309	.884	.0258	37.2	171	-.000012	.001 282	.884	.0254	37.2	174	-.000011	.001 259
477 000	300 000	.883	.0304	43.4	170	-.000014	.001 293	.883	.0298	43.4	173	-.000013	.001 265	.883	.0293	43.4	177	-.000013	.001 245
397 500	250 000	.883	.0359	52.0	173	-.000016	.001 272	.883	.0351	52.0	176	-.000015	.001 247	.883	.0346	52.0	180	-.000015	.001 226
336 400	0 000	.883	.0419	61.5	176	-.000019	.001 256	.883	.0411	61.5	179	-.000018	.001 231	.883	.0404	61.5	182	-.000017	.001 210
266 800	000	.883	.0514	77.4	181	-.000022	.001 224	.883	.0504	77.4	184	-.000021	.001 201	.883	.0496	77.4	187	-.000021	.001 180
0 000	00	.871	.0667	102.	203	-.000028	.001 199	.871	.0655	102.	206	-.000027	.001 176	.872	.0643	102.	209	-.000026	.001 155

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.883	.00979	13.4	164	-.000005	.001 344	.883	.00962	13.4	166	-.000004	.001 321	.883	.00950	13.4	169	-.000004	.001 305
1 510 500	950 000	.883	.0102	14.1	164	-.000005	.001 337	.883	.0101	14.1	167	-.000005	.001 316	.883	.00992	14.1	169	-.000005	.001 298
1 431 000	900 000	.883	.0107	14.8	165	-.000005	.001 330	.883	.0105	14.8	168	-.000005	.001 309	.883	.0104	14.8	170	-.000005	.001 291
1 351 500	850 000	.883	.0113	15.7	166	-.000005	.001 323	.883	.0111	15.7	168	-.000005	.001 305	.883	.0109	15.7	171	-.000005	.001 286
1 272 000	800 000	.883	.0119	16.6	167	-.000006	.001 318	.883	.0117	16.6	169	-.000005	.001 298	.883	.0115	16.6	172	-.000005	.001 279
1 192 500	750 000	.883	.0126	17.7	168	-.000006	.001 309	.883	.0124	17.7	170	-.000006	.001 291	.883	.0122	17.7	173	-.000005	.001 272
1 113 000	700 000	.884	.0134	19.0	168	-.000006	.001 302	.883	.0132	19.0	171	-.000006	.001 284	.883	.0130	19.0	173	-.000006	.001 265
1 033 500	650 000	.884	.0143	20.4	169	-.000007	.001 293	.883	.0141	20.4	172	-.000006	.001 275	.883	.0139	20.4	174	-.000006	.001 259
954 000	600 000	.884	.0154	22.1	170	-.000007	.001 286	.884	.0152	22.1	173	-.000007	.001 268	.884	.0149	22.1	175	-.000007	.001 249
874 500	550 000	.884	.0167	24.1	172	-.000008	.001 277	.884	.0165	24.1	174	-.000007	.001 259	.884	.0162	24.1	176	-.000007	.001 240
795 000	500 000	.884	.0181	26.3	173	-.000008	.001 265	.884	.0178	26.3	176	-.000008	.001 247	.884	.0176	26.3	178	-.000008	.001 231
715 500	450 000	.884	.0200	29.4	175	-.000009	.001 256	.884	.0198	29.4	177	-.000009	.001 238	.884	.0195	29.4	179	-.000008	.001 222
636 000	400 000	.884	.0223	33.0	176	-.000010	.001 245	.884	.0219	33.0	179	-.000009	.001 226	.884	.0216	33.0	181	-.000009	.001 210
556 500	350 000	.884	.0250	37.2	177	-.000011	.001 240	.884	.0246	37.2	179	-.000011	.001 222	.884	.0243	37.2	182	-.000010	.001 206
477 000	300 000	.883	.0288	43.4	179	-.000012	.001 224	.883	.0284	43.4	182	-.000012	.001 208	.884	.0280	43.4	184	-.000012	.001 192
397 500	250 000	.883	.0340	52.0	182	-.000014	.001 208	.883	.0335	52.0	185	-.000014	.001 189	.883	.0332	52.0	187	-.000014	.001 176
336 400	0 000	.883	.0397	61.5	185	-.000017	.001 192	.883	.0392	61.5	187	-.000016	.001 176	.883	.0387	61.5	190	-.000016	.001 159
266 800	000	.883	.0488	77.4	190	-.000020	.001 162	.883	.0482	77.4	193	-.000020	.001 148	.883	.0476	77.4	195	-.000019	.001 134
0 000	00	.872	.0634	102.	212	-.000026	.001 139	.872	.0625	102.	215	-.000025	.001 123	.872	.0619	102.	217	-.000024	.001 112

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXXV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

250 MILES—402.34 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.869	.012 2	14.5	159	−.000 007	.001 540	.869	.011 8	14.5	165	−.000 006	.001 482	.869	.011 4	14.5	170	−.000 006	.001 439
950 000	.869	.012 7	15.2	160	−.000 007	.001 533	.869	.012 2	15.2	166	−.000 006	.001 475	.869	.011 9	15.2	171	−.000 006	.001 432
900 000	.869	.013 3	15.9	161	−.000 007	.001 525	.869	.012 8	15.9	167	−.000 007	.001 468	.869	.012 4	15.9	172	−.000 006	.001 425
850 000	.869	.013 9	16.7	162	−.000 007	.001 516	.869	.013 4	16.7	168	−.000 007	.001 461	.869	.013 0	16.7	172	−.000 007	.001 418
800 000	.869	.014 6	17.6	163	−.000 008	.001 509	.869	.014 0	17.6	168	−.000 007	.001 454	.869	.013 6	17.6	173	−.000 007	.001 411
750 000	.869	.015 3	18.7	164	−.000 008	.001 499	.869	.014 8	18.7	169	−.000 008	.001 444	.869	.014 4	18.7	174	−.000 007	.001 404
700 000	.869	.016 2	19.9	165	−.000 009	.001 490	.869	.015 7	19.9	170	−.000 008	.001 437	.869	.015 2	19.9	175	−.000 008	.001 394
650 000	.869	.017 3	21.3	166	−.000 009	.001 480	.869	.016 7	21.3	172	−.000 008	.001 427	.869	.016 2	21.3	176	−.000 008	.001 384
600 000	.869	.018 5	23.0	167	−.000 010	.001 468	.869	.017 8	23.0	173	−.000 009	.001 415	.869	.017 3	23.0	178	−.000 008	.001 375
550 000	.869	.019 9	24.9	169	−.000 010	.001 456	.869	.019 2	24.9	174	−.000 010	.001 406	.869	.018 6	24.9	179	−.000 009	.001 365
500 000	.869	.021 6	27.3	170	−.000 011	.001 444	.869	.020 8	27.3	176	−.000 010	.001 394	.869	.020 3	27.3	180	−.000 010	.001 356
450 000	.869	.023 6	30.2	171	−.000 012	.001 430	.869	.022 9	30.2	177	−.000 011	.001 382	.869	.022 2	30.2	182	−.000 011	.001 344
400 000	.869	.026 2	33.9	174	−.000 013	.001 415	.869	.025 3	33.9	179	−.000 012	.001 368	.869	.024 6	33.9	184	−.000 012	.001 329
350 000	.869	.029 5	38.6	176	−.000 015	.001 399	.869	.028 5	38.6	181	−.000 014	.001 351	.869	.027 8	38.6	186	−.000 013	.001 315
300 000	.869	.033 9	44.9	178	−.000 017	.001 380	.869	.032 8	44.9	184	−.000 016	.001 334	.869	.031 9	44.9	189	−.000 015	.001 298
250 000	.869	.039 9	53.7	181	−.000 019	.001 358	.869	.038 7	53.7	187	−.000 018	.001 315	.869	.037 6	53.7	192	−.000 017	.001 279
0 000	.868	.046 3	63.3	185	−.000 022	.001 337	.868	.044 8	63.3	191	−.000 021	.001 294	.868	.043 7	63.3	196	−.000 020	.001 260
000	.868	.057 3	79.8	189	−.000 027	.001 313	.868	.055 4	79.8	195	−.000 025	.001 270	.868	.054 0	79.8	200	−.000 024	.001 239
00	.868	.070 9	100.	193	−.000 032	.001 289	.868	.068 6	100.	199	−.000 030	.001 248	.868	.066 9	100.	204	−.000 029	.001 217

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.869	.011 1	14.5	174	−.000 006	.001 404	.869	.010 9	14.5	178	−.000 005	.001 372	.870	.010 7	14.5	181	−.000 005	.001 349
950 000	.869	.011 6	15.2	175	−.000 006	.001 396	.870	.011 3	15.2	179	−.000 006	.001 368	.870	.011 1	15.2	182	−.000 005	.001 341
900 000	.869	.012 1	15.9	176	−.000 006	.001 389	.870	.011 8	15.9	179	−.000 006	.001 360	.870	.011 6	15.9	183	−.000 006	.001 337
850 000	.869	.012 7	16.7	177	−.000 006	.001 384	.870	.012 4	16.7	180	−.000 006	.001 353	.870	.012 2	16.7	183	−.000 006	.001 329
800 000	.869	.013 3	17.6	178	−.000 007	.001 377	.870	.013 0	17.6	181	−.000 006	.001 349	.870	.012 8	17.6	184	−.000 006	.001 322
750 000	.869	.014 0	18.7	178	−.000 007	.001 368	.870	.013 7	18.7	182	−.000 007	.001 341	.870	.013 5	18.7	185	−.000 006	.001 315
700 000	.870	.014 8	19.9	179	−.000 007	.001 360	.870	.014 5	19.9	183	−.000 007	.001 332	.870	.014 3	19.9	186	−.000 007	.001 308
650 000	.870	.015 8	21.3	181	−.000 008	.001 353	.870	.015 5	21.3	184	−.000 007	.001 325	.870	.015 2	21.3	187	−.000 007	.001 301
600 000	.869	.016 9	23.0	182	−.000 008	.001 344	.870	.016 5	23.0	185	−.000 008	.001 315	.870	.016 2	23.0	189	−.000 007	.001 291
550 000	.869	.018 2	24.9	183	−.000 009	.001 334	.870	.017 8	24.9	187	−.000 008	.001 305	.870	.017 5	24.9	190	−.000 008	.001 284
500 000	.869	.019 8	27.3	185	−.000 009	.001 322	.870	.019 4	27.3	188	−.000 009	.001 296	.870	.019 1	27.3	191	−.000 009	.001 274
450 000	.869	.021 7	30.2	186	−.000 010	.001 313	.870	.021 3	30.2	190	−.000 010	.001 286	.870	.020 9	30.2	193	−.000 009	.001 262
400 000	.869	.024 1	33.9	188	−.000 011	.001 298	.870	.023 6	33.9	192	−.000 011	.001 272	.870	.023 2	33.9	195	−.000 010	.001 250
350 000	.869	.027 1	38.6	190	−.000 012	.001 284	.870	.026 6	38.6	194	−.000 012	.001 260	.870	.026 1	38.6	197	−.000 011	.001 239
300 000	.869	.031 2	44.9	193	−.000 014	.001 270	.870	.030 5	44.9	196	−.000 013	.001 243	.870	.030 1	44.9	200	−.000 013	.001 224
250 000	.869	.036 8	53.7	196	−.000 016	.001 250	.870	.036 1	53.7	199	−.000 016	.001 227	.870	.035 5	53.7	203	−.000 015	.001 207
0 000	.868	.042 8	63.3	200	−.000 019	.001 234	.869	.042 0	63.3	203	−.000 018	.001 210	.869	.041 3	63.3	207	−.000 017	.001 191
000	.868	.052 9	79.8	204	−.000 023	.001 212	.869	.051 9	79.8	207	−.000 022	.001 188	.869	.051 0	79.8	211	−.000 021	.001 169
00	.868	.065 5	100.	208	−.000 028	.001 191	.869	.064 3	100.	212	−.000 027	.001 169	.869	.063 2	100.	215	−.000 026	.001 150

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.870	.010 5	14.5	184	−.000 005	.001 325	.870	.010 4	14.5	187	−.000 005	.001 305	.870	.010 2	14.5	189	−.000 005	.001 289
950 000	.870	.010 9	15.2	185	−.000 005	.001 320	.870	.010 8	15.2	187	−.000 005	.001 301	.870	.010 7	15.2	190	−.000 005	.001 284
900 000	.870	.011 4	15.9	186	−.000 005	.001 315	.870	.011 3	15.9	188	−.000 005	.001 296	.870	.011 1	15.9	191	−.000 005	.001 277
850 000	.870	.012 0	16.7	186	−.000 006	.001 308	.870	.011 8	16.7	189	−.000 005	.001 289	.870	.011 6	16.7	191	−.000 005	.001 272
800 000	.870	.012 6	17.6	187	−.000 006	.001 301	.870	.012 4	17.6	190	−.000 006	.001 282	.870	.012 2	17.6	192	−.000 005	.001 265
750 000	.870	.013 2	18.7	188	−.000 006	.001 294	.870	.013 1	18.7	191	−.000 006	.001 277	.870	.012 9	18.7	193	−.000 006	.001 260
700 000	.870	.014 0	19.9	189	−.000 006	.001 286	.870	.013 8	19.9	192	−.000 006	.001 270	.870	.013 7	19.9	194	−.000 006	.001 253
650 000	.870	.014 9	21.3	190	−.000 007	.001 279	.870	.014 7	21.3	193	−.000 007	.001 262	.870	.014 5	21.3	195	−.000 006	.001 246
600 000	.870	.016 0	23.0	192	−.000 007	.001 272	.870	.015 8	23.0	194	−.000 007	.001 253	.870	.015 6	23.0	197	−.000 007	.001 239
550 000	.870	.017 2	24.9	193	−.000 008	.001 262	.870	.017 0	24.9	196	−.000 008	.001 246	.870	.016 8	24.9	198	−.000 007	.001 229
500 000	.870	.018 7	27.3	194	−.000 008	.001 253	.870	.018 5	27.3	197	−.000 008	.001 236	.870	.018 2	27.3	199	−.000 008	.001 219
450 000	.870	.020 6	30.2	196	−.000 009	.001 243	.870	.020 3	30.2	199	−.000 009	.001 227	.870	.020 0	30.2	201	−.000 009	.001 210
400 000	.870	.022 8	33.9	198	−.000 010	.001 231	.870	.022 5	33.9	201	−.000 010	.001 215	.870	.022 2	33.9	203	−.000 009	.001 200
350 000	.870	.025 7	38.6	200	−.000 011	.001 219	.870	.025 4	38.6	203	−.000 011	.001 203	.870	.025 1	38.6	205	−.000 011	.001 188
300 000	.870	.029 6	44.9	203	−.000 013	.001 205	.870	.029 2	44.9	205	−.000 012	.001 188	.870	.028 8	44.9	208	−.000 012	.001 174
250 000	.870	.034 9	53.7	205	−.000 015	.001 188	.870	.034 1	53.7	208	−.000 014	.001 174	.870	.034 1	53.7	210	−.000 014	.001 160
0 000	.869	.040 6	63.3	210	−.000 017	.001 172	.869	.040 1	63.3	212	−.000 016	.001 157	.869	.039 6	63.3	215	−.000 016	.001 143
000	.869	.050 3	79.8	214	−.000 021	.001 152	.869	.049 7	79.8	216	−.000 020	.001 138	.869	.049 1	79.8	219	−.000 020	.001 124
00	.869	.062 3	100.	218	−.000 025	.001 133	.869	.061 5	100.	220	−.000 024	.001 119	.869	.060 9	100.	223	.000 024	.001 107

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXXVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

250 MILES—402.34 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN. 61%	9 FEET—2.743 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	11 FEET—3.353 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	13 FEET—3.962 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.873	.0124	13.9	146	-.000 007	.001 632	.873	.0119	13.9	151	-.000 007	.001 570	.873	.0115	13.9	156	-.000 006	.001 520
1 510 500	950 000	.873	.0129	14.6	146	-.000 007	.001 625	.873	.0124	14.6	152	-.000 007	.001 560	.873	.0120	14.6	157	-.000 006	.001 512
1 431 000	900 000	.873	.0135	15.4	147	-.000 008	.001 615	.873	.0130	15.4	153	-.000 007	.001 553	.873	.0126	15.4	158	-.000 007	.001 505
1 351 500	850 000	.874	.0142	16.2	148	-.000 008	.001 606	.874	.0137	16.2	154	-.000 007	.001 543	.874	.0133	16.2	158	-.000 007	.001 496
1 272 000	800 000	.874	.0150	17.2	149	-.000 008	.001 596	.874	.0144	17.2	154	-.000 008	.001 536	.874	.0140	17.2	159	-.000 007	.001 488
1 192 500	750 000	.874	.0159	18.3	149	-.000 009	.001 587	.874	.0153	18.3	155	-.000 008	.001 527	.874	.0148	18.3	160	-.000 008	.001 479
1 113 000	700 000	.874	.0169	19.6	150	-.000 009	.001 577	.874	.0162	19.6	156	-.000 009	.001 517	.874	.0158	19.6	161	-.000 008	.001 472
1 033 500	650 000	.874	.0180	21.1	151	-.000 010	.001 565	.874	.0173	21.1	157	-.000 009	.001 505	.874	.0168	21.1	162	-.000 009	.001 460
954 000	600 000	.874	.0194	22.8	153	-.000 011	.001 553	.874	.0186	22.8	158	-.000 010	.001 496	.874	.0181	22.8	163	-.000 009	.001 450
874 500	550 000	.874	.0210	24.9	154	-.000 011	.001 539	.874	.0202	24.9	160	-.000 011	.001 481	.874	.0196	24.9	164	-.000 010	.001 438
795 000	500 000	.874	.0227	27.2	155	-.000 012	.001 527	.874	.0219	27.2	161	-.000 011	.001 469	.874	.0212	27.2	166	-.000 011	.001 426
715 500	450 000	.874	.0251	30.4	157	-.000 013	.001 510	.874	.0242	30.4	163	-.000 013	.001 457	.874	.0235	30.4	167	-.000 012	.001 412
636 000	400 000	.874	.0278	34.1	159	-.000 015	.001 493	.874	.0268	34.1	164	-.000 014	.001 441	.874	.0260	34.1	169	-.000 013	.001 398
556 500	350 000	.874	.0313	38.4	159	-.000 016	.001 488	.874	.0301	38.4	165	-.000 015	.001 433	.874	.0292	38.4	170	-.000 014	.001 393
477 000	300 000	.874	.0359	44.8	162	-.000 019	.001 467	.874	.0346	44.8	168	-.000 017	.001 414	.874	.0337	44.8	172	-.000 016	.001 376
397 500	250 000	.873	.0424	53.7	165	-.000 022	.001 443	.873	.0409	53.7	171	-.000 020	.001 393	.873	.0398	53.7	176	-.000 019	.001 354
336 400	0 000	.873	.0494	63.6	168	-.000 025	.001 421	.873	.0477	63.6	173	-.000 023	.001 374	.873	.0464	63.6	178	-.000 022	.001 335
266 800	000	.873	.0605	80.1	173	-.000 030	.001 383	.873	.0584	80.1	179	-.000 028	.001 335	.873	.0569	80.1	184	-.000 026	.001 302
0000	00	.859	.0783	105.	196	-.000 038	.001 351	.859	.0757	105.	202	-.000 035	.001 305	.860	.0738	105.	207	-.000 033	.001 272

		15 FEET—4.572 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	17 FEET—5.182 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	19 FEET—5.791 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.873	.0112	13.9	160	-.000 006	.001 479	.873	.0110	13.9	164	-.000 006	.001 445	.873	.0108	13.9	167	-.000 005	.001 419
1 510 500	950 000	.873	.0117	14.6	161	-.000 006	.001 472	.873	.0115	14.6	165	-.000 006	.001 441	.874	.0112	14.6	168	-.000 006	.001 412
1 431 000	900 000	.873	.0123	15.4	162	-.000 006	.001 465	.873	.0120	15.4	166	-.000 006	.001 433	.874	.0118	15.4	169	-.000 006	.001 405
1 351 500	850 000	.874	.0129	16.2	163	-.000 007	.001 457	.874	.0126	16.2	166	-.000 006	.001 426	.874	.0124	16.2	169	-.000 006	.001 398
1 272 000	800 000	.874	.0136	17.2	163	-.000 007	.001 450	.874	.0133	17.2	167	-.000 007	.001 419	.874	.0131	17.2	170	-.000 006	.001 390
1 192 500	750 000	.874	.0144	18.3	164	-.000 007	.001 441	.874	.0141	18.3	168	-.000 007	.001 409	.874	.0138	18.3	171	-.000 007	.001 383
1 113 000	700 000	.874	.0154	19.6	165	-.000 008	.001 433	.874	.0150	19.6	169	-.000 007	.001 402	.874	.0147	19.6	172	-.000 007	.001 376
1 033 500	650 000	.874	.0164	21.1	166	-.000 008	.001 424	.874	.0160	21.1	170	-.000 008	.001 393	.874	.0157	21.1	173	-.000 008	.001 366
954 000	600 000	.874	.0176	22.8	167	-.000 009	.001 414	.874	.0172	22.8	171	-.000 008	.001 383	.874	.0169	22.8	174	-.000 008	.001 357
874 500	550 000	.874	.0191	24.9	168	-.000 009	.001 402	.874	.0187	24.9	172	-.000 009	.001 374	.874	.0184	24.9	175	-.000 009	.001 347
795 000	500 000	.874	.0207	27.2	170	-.000 010	.001 390	.874	.0203	27.2	174	-.000 010	.001 362	.874	.0199	27.2	177	-.000 009	.001 338
715 500	450 000	.874	.0229	30.4	172	-.000 011	.001 378	.874	.0224	30.4	175	-.000 011	.001 350	.874	.0220	30.4	178	-.000 010	.001 326
636 000	400 000	.874	.0254	34.1	173	-.000 012	.001 364	.874	.0249	34.1	177	-.000 012	.001 338	.874	.0245	34.1	180	-.000 011	.001 314
556 500	350 000	.874	.0285	38.4	174	-.000 014	.001 359	.874	.0279	38.4	178	-.000 013	.001 331	.874	.0274	38.4	181	-.000 013	.001 307
477 000	300 000	.874	.0329	44.8	176	-.000 016	.001 342	.874	.0322	44.8	180	-.000 015	.001 314	.874	.0316	44.8	184	-.000 014	.001 292
397 500	250 000	.873	.0388	53.7	180	-.000 018	.001 321	.873	.0380	53.7	183	-.000 017	.001 295	.873	.0374	53.7	186	-.000 017	.001 273
336 400	0 000	.873	.0453	63.6	183	-.000 021	.001 304	.873	.0444	63.6	186	-.000 020	.001 278	.873	.0437	63.6	189	-.000 019	.001 256
266 800	000	.873	.0556	80.1	188	-.000 025	.001 271	.873	.0545	80.1	191	-.000 024	.001 247	.873	.0536	80.1	195	-.000 023	.001 225
0000	00	.860	.0721	105.	211	-.000 032	.001 243	.860	.0708	105.	214	-.000 031	.001 221	.861	.0695	105.	218	-.000 030	.001 199

		21 FEET—6.401 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	23 FEET—7.010 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2	25 FEET—7.620 METERS A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.873	.0106	13.9	170	-.000 005	.001 395	.873	.0104	13.9	173	-.000 005	.001 371	.873	.0103	13.9	175	-.000 005	.001 354
1 510 500	950 000	.874	.0111	14.6	171	-.000 005	.001 388	.874	.0109	14.6	173	-.000 005	.001 366	.874	.0107	14.6	176	-.000 005	.001 347
1 431 000	900 000	.874	.0116	15.4	171	-.000 006	.001 381	.874	.0114	15.4	174	-.000 005	.001 359	.874	.0112	15.4	177	-.000 005	.001 340
1 351 500	850 000	.874	.0122	16.2	172	-.000 006	.001 374	.874	.0120	16.2	175	-.000 006	.001 354	.874	.0118	16.2	177	-.000 006	.001 335
1 272 000	800 000	.874	.0129	17.2	173	-.000 006	.001 369	.874	.0127	17.2	176	-.000 006	.001 347	.874	.0125	17.2	178	-.000 006	.001 328
1 192 500	750 000	.874	.0136	18.3	174	-.000 007	.001 359	.874	.0134	18.3	177	-.000 006	.001 340	.874	.0132	18.3	179	-.000 006	.001 321
1 113 000	700 000	.874	.0145	19.6	175	-.000 007	.001 352	.874	.0143	19.6	177	-.000 007	.001 333	.874	.0141	19.6	180	-.000 007	.001 314
1 033 500	650 000	.874	.0155	21.1	176	-.000 007	.001 342	.874	.0153	21.1	178	-.000 007	.001 323	.874	.0151	21.1	181	-.000 007	.001 307
954 000	600 000	.874	.0166	22.8	177	-.000 008	.001 335	.874	.0164	22.8	180	-.000 008	.001 316	.874	.0162	22.8	182	-.000 007	.001 297
874 500	550 000	.874	.0181	24.9	178	-.000 008	.001 326	.874	.0178	24.9	181	-.000 008	.001 307	.874	.0175	24.9	183	-.000 008	.001 287
795 000	500 000	.874	.0195	27.2	180	-.000 009	.001 314	.874	.0193	27.2	182	-.000 009	.001 295	.874	.0190	27.2	185	-.000 009	.001 278
715 500	450 000	.874	.0217	30.4	181	-.000 010	.001 304	.874	.0214	30.4	184	-.000 010	.001 285	.874	.0211	30.4	186	-.000 009	.001 268
636 000	400 000	.874	.0241	34.1	183	-.000 011	.001 292	.874	.0237	34.1	186	-.000 011	.001 273	.874	.0234	34.1	188	-.000 010	.001 256
556 500	350 000	.874	.0270	38.4	184	-.000 012	.001 287	.874	.0266	38.4	186	-.000 012	.001 268	.874	.0263	38.4	189	-.000 012	.001 252
477 000	300 000	.874	.0311	44.8	186	-.000 014	.001 271	.874	.0307	44.8	189	-.000 014	.001 254	.874	.0303	44.8	191	-.000 013	.001 237
397 500	250 000	.873	.0368	53.7	189	-.000 016	.001 254	.874	.0363	53.7	192	-.000 016	.001 235	.874	.0359	53.7	194	-.000 016	.001 220
336 400	0 000	.873	.0430	63.6	192	-.000 019	.001 237	.874	.0424	63.6	195	-.000 018	.001 220	.874	.0418	63.6	197	-.000 018	.001 204
266 800	000	.873	.0527	80.1	197	-.000 023	.001 206	.873	.0521	80.1	200	-.000 022	.001 192	.873	.0515	80.1	202	-.000 021	.001 177
0000	00	.861	.0685	105.	220	-.000 029	.001 182	.861	.0676	105.	223	-.000 028	.001 166	.861	.0669	105.	225	-.000 027	.001 154

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE LXXXVII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

260 MILES—418.43 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.858	.013 2	15.0	165	-.000 008	.001 595	.859	.012 7	15.0	171	-.000 007	.001 535	.859	.012 3	15.0	176	-.000 007	.001 491
950 000	.858	.013 7	15.6	166	-.000 008	.001 587	.859	.013 2	15.6	172	-.000 007	.001 528	.859	.012 8	15.6	177	-.000 007	.001 483
900 000	.858	.014 3	16.4	167	-.000 008	.001 580	.859	.013 8	16.4	173	-.000 007	.001 520	.859	.013 4	16.4	178	-.000 007	.001 476
850 000	.858	.014 9	17.2	167	-.000 008	.001 570	.859	.014 4	17.2	174	-.000 008	.001 513	.859	.014 0	17.2	179	-.000 007	.001 468
800 000	.858	.015 7	18.2	168	-.000 009	.001 562	.859	.015 1	18.2	174	-.000 008	.001 505	.859	.014 7	18.2	180	-.000 008	.001 461
750 000	.858	.016 5	19.3	169	-.000 009	.001 552	.859	.015 9	19.3	175	-.000 009	.001 496	.859	.015 5	19.3	181	-.000 008	.001 453
700 000	.859	.017 5	20.5	170	-.000 010	.001 543	.859	.016 9	20.5	176	-.000 009	.001 488	.859	.016 4	20.5	182	-.000 008	.001 444
650 000	.859	.018 6	22.0	172	-.000 010	.001 533	.859	.017 9	22.0	178	-.000 009	.001 478	.859	.017 4	22.0	183	-.000 009	.001 434
600 000	.859	.019 9	23.7	173	-.000 011	.001 520	.859	.019 2	23.7	179	-.000 010	.001 466	.859	.018 6	23.7	184	-.000 009	.001 424
550 000	.859	.021 4	25.7	175	-.000 012	.001 508	.859	.020 7	25.7	180	-.000 011	.001 456	.859	.020 1	25.7	185	-.000 010	.001 414
500 000	.859	.023 3	28.2	176	-.000 012	.001 496	.859	.022 5	28.2	182	-.000 012	.001 444	.859	.021 8	28.2	187	-.000 011	.001 404
450 000	.859	.025 5	31.2	178	-.000 013	.001 481	.859	.024 6	31.2	184	-.000 013	.001 431	.859	.023 9	31.2	188	-.000 012	.001 392
400 000	.859	.028 3	34.9	180	-.000 015	.001 466	.859	.027 3	34.9	186	-.000 014	.001 416	.859	.026 5	34.9	191	-.000 013	.001 377
350 000	.859	.031 8	39.8	182	-.000 016	.001 448	.859	.030 7	39.8	188	-.000 015	.001 399	.859	.029 9	39.8	193	-.000 015	.001 362
300 000	.859	.036 5	46.3	184	-.000 019	.001 429	.859	.035 3	46.3	191	-.000 017	.001 382	.859	.034 4	46.3	195	-.000 017	.001 344
250 000	.859	.043 0	55.4	187	-.000 022	.001 406	.859	.041 7	55.4	193	-.000 020	.001 362	.859	.040 5	55.4	198	-.000 019	.001 325
0 000	.858	.049 9	65.4	192	-.000 025	.001 384	.858	.048 3	65.4	198	-.000 023	.001 340	.858	.047 1	65.4	203	-.000 022	.001 305
000	.857	.061 7	82.3	196	-.000 030	.001 359	.858	.059 7	82.3	202	-.000 028	.001 315	.858	.058 2	82.3	207	-.000 027	.001 283
00	.857	.076 3	104.	201	-.000 036	.001 335	.857	.073 9	104.	207	-.000 034	.001 292	.858	.072 1	104.	212	-.000 032	.001 260

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.859	.012 0	15.0	180	-.000 006	.001 453	.859	.011 7	15.0	184	-.000 006	.001 421	.859	.011 5	15.0	187	-.000 006	.001 396
950 000	.859	.012 5	15.6	181	-.000 006	.001 446	.859	.012 2	15.6	185	-.000 006	.001 416	.859	.012 0	15.6	188	-.000 006	.001 389
900 000	.859	.013 0	16.4	182	-.000 007	.001 439	.859	.012 7	16.4	186	-.000 006	.001 409	.859	.012 5	16.4	189	-.000 006	.001 384
850 000	.859	.013 6	17.2	183	-.000 007	.001 434	.859	.013 3	17.2	187	-.000 007	.001 401	.859	.013 1	17.2	190	-.000 006	.001 377
800 000	.859	.014 3	18.2	184	-.000 007	.001 426	.859	.014 0	18.2	188	-.000 007	.001 396	.859	.013 7	18.2	191	-.000 007	.001 369
750 000	.859	.015 1	19.3	185	-.000 008	.001 416	.859	.014 8	19.3	189	-.000 007	.001 389	.859	.014 5	19.3	192	-.000 007	.001 362
700 000	.859	.016 0	20.5	186	-.000 008	.001 409	.859	.015 6	20.5	190	-.000 008	.001 379	.859	.015 4	20.5	193	-.000 007	.001 354
650 000	.859	.017 0	22.0	187	-.000 009	.001 401	.859	.016 7	22.0	191	-.000 008	.001 372	.859	.016 4	22.0	194	-.000 008	.001 347
600 000	.859	.018 2	23.7	188	-.000 009	.001 392	.859	.017 8	23.7	192	-.000 009	.001 362	.859	.017 5	23.7	196	-.000 008	.001 337
550 000	.859	.019 6	25.7	190	-.000 010	.001 382	.859	.019 2	25.7	194	-.000 009	.001 352	.859	.018 9	25.7	197	-.000 009	.001 330
500 000	.859	.021 3	28.2	191	-.000 010	.001 369	.859	.020 9	28.2	195	-.000 010	.001 342	.859	.020 5	28.2	198	-.000 010	.001 320
450 000	.859	.023 4	31.2	193	-.000 011	.001 359	.859	.022 9	31.2	197	-.000 011	.001 332	.859	.022 5	31.2	200	-.000 011	.001 307
400 000	.859	.025 9	34.9	195	-.000 012	.001 344	.859	.025 4	34.9	199	-.000 012	.001 317	.859	.025 0	34.9	202	-.000 012	.001 295
350 000	.859	.029 2	39.8	197	-.000 014	.001 330	.859	.028 7	39.8	201	-.000 013	.001 305	.859	.028 2	39.8	204	-.000 013	.001 283
300 000	.859	.033 6	46.3	200	-.000 016	.001 315	.859	.032 9	46.3	203	-.000 015	.001 288	.859	.032 4	46.3	207	-.000 015	.001 268
250 000	.859	.039 6	55.4	203	-.000 018	.001 295	.859	.038 9	55.4	207	-.000 018	.001 270	.859	.038 3	55.4	210	-.000 017	.001 250
0 000	.858	.046 1	65.4	207	-.000 021	.001 278	.858	.045 2	65.4	211	-.000 020	.001 253	.858	.044 5	65.4	214	-.000 020	.001 233
000	.858	.057 0	82.3	211	-.000 026	.001 255	.858	.055 9	82.3	215	-.000 025	.001 231	.858	.055 0	82.3	218	-.000 024	.001 211
00	.858	.070 5	104.	216	-.000 031	.001 233	.858	.069 3	104.	219	-.000 030	.001 211	.858	.068-1	104.	223	-.000 029	.001 191

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.859	.011 3	15.0	190	-.000 006	.001 372	.859	.011 2	15.0	193	-.000 005	.001 352	.860	.011 0	15.0	196	-.000 005	.001 335
950 000	.859	.011 8	15.6	191	-.000 006	.001 367	.859	.011 6	15.6	194	-.000 006	.001 347	.860	.011 5	15.6	197	-.000 005	.001 330
900 000	.859	.012 3	16.4	192	-.000 006	.001 362	.859	.012 1	16.4	195	-.000 006	.001 342	.860	.012 0	16.4	197	-.000 006	.001 322
850 000	.859	.012 9	17.2	193	-.000 006	.001 354	.860	.012 7	17.2	196	-.000 006	.001 335	.860	.012 5	17.2	198	-.000 006	.001 317
800 000	.859	.013 5	18.2	194	-.000 007	.001 347	.860	.013 3	18.2	197	-.000 006	.001 327	.860	.013 2	18.2	199	-.000 006	.001 310
750 000	.860	.014 3	19.3	195	-.000 007	.001 340	.860	.014 1	19.3	198	-.000 007	.001 322	.860	.013 9	19.3	200	-.000 006	.001 305
700 000	.860	.015 1	20.5	196	-.000 007	.001 332	.860	.014 9	20.5	199	-.000 007	.001 315	.860	.014 7	20.5	201	-.000 007	.001 297
650 000	.860	.016 1	22.0	197	-.000 008	.001 325	.860	.015 9	22.0	200	-.000 007	.001 307	.860	.015 7	22.0	202	-.000 007	.001 290
600 000	.859	.017 2	23.7	198	-.000 008	.001 317	.860	.017 0	23.7	201	-.000 008	.001 297	.860	.016 8	23.7	204	-.000 008	.001 283
550 000	.859	.018 6	25.7	200	-.000 009	.001 307	.860	.018 3	25.7	202	-.000 008	.001 290	.860	.018 1	25.7	205	-.000 008	.001 273
500 000	.859	.020 2	28.2	201	-.000 009	.001 297	.860	.019 9	28.2	204	-.000 009	.001 280	.860	.019 6	28.2	206	-.000 009	.001 263
450 000	.859	.022 1	31.2	203	-.000 010	.001 288	.859	.021 8	31.2	206	-.000 010	.001 270	.860	.021 6	31.2	208	-.000 010	.001 253
400 000	.859	.024 6	34.9	205	-.000 011	.001 275	.859	.024 3	34.9	208	-.000 011	.001 258	.859	.024 0	34.9	211	-.000 011	.001 243
350 000	.859	.027 7	39.8	207	-.000 013	.001 263	.859	.027 3	39.8	210	-.000 012	.001 245	.859	.027 0	39.8	213	-.000 012	.001 231
300 000	.859	.031 9	46.3	210	-.000 014	.001 248	.859	.031 4	46.3	212	-.000 014	.001 231	.859	.031 1	46.3	215	-.000 013	.001 216
250 000	.859	.037 6	55.4	213	-.000 017	.001 231	.859	.037 2	55.4	215	-.000 016	.001 216	.859	.036 7	55.4	218	-.000 016	.001 201
0 000	.859	.043 8	65.4	217	-.000 019	.001 213	.859	.043 2	65.4	220	-.000 019	.001 198	.859	.042 7	65.4	222	-.000 018	.001 184
000	.858	.054 2	82.3	221	-.000 023	.001 193	.858	.053 5	82.3	224	-.000 023	.001 179	.859	.052 9	82.3	226	-.000 022	.001 164
00	.858	.067 1	104.	226	-.000 028	.001 174	.858	.066 3	104.	228	-.000 027	.001 159	.858	.065 6	104.	231	-.000 027	.001 146

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} - \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE LXXXVIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

260 MILES—418.43 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.863	0133	14.3	151	-.000008	.001691	.863	.0128	14.3	157	-.000007	.001627	.863	.0124	14.3	162	-.000007	.001575
1 510 500	950 000	.863	.0139	15.0	151	-.000008	.001684	.863	.0134	15.0	158	-.000008	.001617	.863	.0130	15.0	163	-.000007	.001567
1 431 000	900 000	.863	0146	15.8	152	-.000009	.001674	.863	.0140	15.8	158	-.000008	.001610	.863	.0136	15.8	163	-.000008	.001560
1 351 500	850 000	.863	.0153	16.7	153	-.000009	.001664	.863	.0147	16.7	159	-.000008	.001600	.863	.0143	16.7	164	-.000008	.001550
1 272 000	800 000	.863	.0162	17.8	154	-.000010	.001654	.863	.0156	17.8	160	-.000009	.001592	.863	.0151	17.8	165	-.000008	.001543
1 192 500	750 000	.863	.0171	18.9	155	-.000010	.001644	.864	.0165	18.9	161	-.000009	.001582	.864	.0160	18.9	166	-.000009	.001533
1 113 000	700 000	.863	.0182	20.2	156	-.000011	.001634	.864	.0175	20.2	162	-.000010	.001572	.864	.0170	20.2	167	-.000009	.001525
1 033 500	650 000	.863	.0194	21.8	157	-.000011	.001622	.864	.0187	21.8	163	-.000010	.001560	.864	.0181	21.8	168	-.000010	.001513
954 000	600 000	.863	.0209	23.5	158	-.000012	.001610	.864	.0201	23.5	164	-.000011	.001550	.864	.0195	23.5	169	-.000010	.001503
874 500	550 000	.864	.0226	25.7	159	-.000013	.001595	.864	.0217	25.7	165	-.000012	.001535	.864	.0211	25.7	170	-.000011	.001490
795 000	500 000	.864	.0245	28.1	161	-.000014	.001582	.864	.0235	28.1	167	-.000013	.001523	.864	.0229	28.1	172	-.000012	.001478
715 500	450 000	.864	.0270	31.4	162	-.000015	.001565	.864	.0261	31.4	168	-.000014	.001510	.864	.0253	31.4	173	-.000013	.001463
636 000	400 000	.864	.0300	35.2	164	-.000017	.001548	.864	.0289	35.2	170	-.000015	.001493	.864	.0280	35.2	175	-.000014	.001448
556 500	350 000	.863	.0337	39.7	165	-.000019	.001543	.864	.0324	39.7	171	-.000017	.001486	.864	.0315	39.7	176	-.000016	.001443
477 000	300 000	.863	.0387	46.3	168	-.000021	.001520	.864	.0373	46.3	174	-.000019	.001466	.864	.0363	46.3	179	-.000018	.001426
397 500	250 000	.863	.0457	55.5	171	-.000024	.001495	.863	.0441	55.5	177	-.000023	.001443	.863	.0429	55.5	182	-.000021	.001404
336 400	0000	.863	.0532	65.6	174	-.000028	.001473	.863	.0514	65.6	180	-.000026	.001424	.863	.0500	65.6	185	-.000025	.001384
266 800	000	.863	.0652	82.6	179	-.000033	.001433	.863	.0629	82.6	185	-.000031	.001384	.863	.0614	82.6	190	-.000029	.001349
0000	00	.848	.0844	108.	203	-.000042	.001399	.848	.0815	108.	209	-.000040	.001352	.848	.0794	108.	214	-.000038	.001318

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	863	.0121	14.3	166	-.000007	.001533	.863	.0118	14.3	170	-.000006	.001498	.863	.0116	14.3	174	-.000006	.001471
1 510 500	950 000	863	.0126	15.0	167	-.000007	.001525	.863	.0124	15.0	171	-.000007	.001493	.863	.0121	15.0	174	-.000006	.001463
1 431 000	900 000	863	.0132	15.8	168	-.000007	.001518	.863	.0130	15.8	172	-.000007	.001486	.864	.0127	15.8	175	-.000007	.001456
1 351 500	850 000	863	.0139	16.7	169	-.000007	.001510	.863	.0136	16.7	172	-.000007	.001478	.864	.0133	16.7	175	-.000007	.001448
1 272 000	800 000	863	.0147	17.8	169	-.000008	.001503	.863	.0144	17.8	173	-.000008	.001471	.864	.0141	17.8	176	-.000007	.001441
1 192 500	750 000	864	.0155	18.9	170	-.000008	.001493	.864	.0152	18.9	174	-.000008	.001461	.864	.0149	18.9	177	-.000008	.001433
1 113 000	700 000	864	.01[illegible]5	20.2	171	-.000009	.001486	.864	.0162	20.2	175	-.000008	.001453	.864	.0159	20.2	178	-.000008	.001426
1 033 500	650 000	864	.0177	21.8	172	-.000009	.001476	.864	.0173	21.8	176	-.000009	.001443	.864	.0170	21.8	179	-.000009	.001416
954 000	600 000	864	.0190	23.5	174	-.000010	.001466	.864	.0186	23.5	177	-.000009	.001433	.864	.0182	23.5	181	-.000009	.001406
874 500	550 000	864	.0206	25.7	175	-.000011	.001453	.864	.0202	25.7	179	-.000010	.001424	.864	.0198	25.7	182	-.000010	.001396
795 000	500 000	864	.0223	28.1	176	-.000011	.001441	.864	.0218	28.1	180	-.000011	.001411	.864	.0214	28.1	183	-.000011	.001386
715 500	450 000	864	.0247	31.4	178	-.000013	.001428	.864	.0242	31.4	182	-.000012	.001399	.864	.0237	31.4	185	-.000012	.001374
636 000	400 000	864	.0274	35.2	180	-.000014	.001414	.864	.0268	35.2	183	-.000013	.001386	.864	.0264	35.2	187	-.000013	.001362
556 500	350 000	864	.0307	39.7	180	-.000015	.001409	.864	.0301	39.7	184	-.000015	.001379	.864	.0296	39.7	187	-.000014	.001354
477 000	300 000	864	.0354	46.3	183	-.000018	.001391	.864	.0347	46.3	187	-.000017	.001362	.864	.0341	46.3	190	-.000016	.001339
397 500	250 000	864	.0418	55.5	186	-.000020	.001369	.864	.0410	55.5	190	-.000020	.001342	.864	.0403	55.5	193	-.000019	.001319
336 400	0000	863	.0488	65.6	189	-.000024	.001352	.863	.0479	65.6	193	-.000023	.001324	.863	.0470	65.6	196	-.000022	.001302
266 800	000	863	.0599	82.6	195	-.000028	.001317	.863	.0588	82.6	198	-.000027	.001292	.863	.0577	82.6	202	-.000026	.001270
0000	00	849	.0777	108.	218	-.000036	.001288	.849	.0762	109.	222	-.000035	.001265	.850	.0749	109.	226	-.000033	.001242

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.863	.0114	14.3	176	-.000006	.001446	.863	.0112	14.3	179	-.000006	.001421	.863	.0111	14.3	182	-.000006	.001404
1 510 500	950 000	.864	.0119	15.0	177	-.000006	.001438	.864	.0117	15.0	180	-.000006	.001416	.864	.0116	15.0	182	-.000006	.001396
1 431 000	900 000	.864	.0125	15.8	178	-.000006	.001431	.864	.0123	15.8	180	-.000006	.001409	.864	.0121	15.8	183	-.000006	.001389
1 351 500	850 000	.864	.0131	16.7	178	-.000007	.001424	.864	.0129	16.7	181	-.000006	.001404	.864	.0128	16.7	184	-.000006	.001384
1 272 000	800 000	.864	.0139	17.8	179	-.000007	.001419	.864	.0136	17.8	182	-.000007	.001396	.864	.0135	17.8	185	-.000007	.001376
1 192 500	750 000	.864	.0147	18.9	180	-.000007	.001409	.864	.0145	18.9	183	-.000007	.001389	.864	.0143	18.9	186	-.000007	.001369
1 113 000	700 000	.864	.0156	20.2	181	-.000008	.001401	.864	.0154	20.2	184	-.000008	.001381	.864	.0152	20.2	186	-.000007	.001362
1 033 500	650 000	.864	.0167	21.8	182	-.000008	.001391	.864	.0164	21.8	185	-.000008	.001371	.864	.0162	21.8	188	-.000008	.001354
954 000	600 000	.864	.0179	23.5	184	-.000009	.001384	.864	.0177	23.5	186	-.000009	.001364	.864	.0174	23.5	189	-.000008	.001344
874 500	550 000	.864	.0195	25.7	185	-.000010	.001374	.864	.0192	25.7	187	-.000009	.001354	.864	.0189	25.7	190	-.000009	.001334
795 000	500 000	.864	.0211	28.1	186	-.000010	.001362	.864	.0207	28.1	189	-.000010	.001342	.864	.0205	28.1	191	-.000010	.001324
715 500	450 000	.864	.0234	31.4	188	-.000011	.001352	.864	.0230	31.4	191	-.000011	.001332	.864	.0227	31.4	193	-.000011	.001314
636 000	400 000	.864	.0259	35.2	190	-.000012	.001339	.864	.0255	35.2	192	-.000012	.001319	.864	.0252	35.2	195	-.000012	.001302
556 500	350 000	.864	.0291	39.7	190	-.000014	.001334	.864	.0287	39.7	193	-.000013	.001314	.864	.0283	39.7	196	-.000013	.001297
477 000	300 000	.864	.0335	46.3	193	-.000016	.001317	.864	.0331	46.3	196	-.000015	.001300	.864	.0326	46.3	198	-.000015	.001282
397 500	250 000	.864	.0397	55.5	196	-.000018	.001300	.864	.0391	55.5	199	-.000018	.001280	.864	.0386	55.5	201	-.000017	.001265
336 400	0000	.863	.0463	65.6	199	-.000021	.001282	.863	.0457	65.6	202	-.000021	.001265	.863	.0450	65.6	205	-.000020	.001247
266 800	000	.863	.0568	82.6	205	-.000025	.001250	.863	.0562	82.6	207	-.000025	.001235	.863	.0555	82.6	210	-.000024	.001220
0000	00	.850	.0738	109.	229	-.000032	.001225	.850	.0728	109.	231	-.000032	.001208	.850	.0721	109.	234	-.000031	.001195

$$A = \cosh\theta = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40{,}320}+\right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing   Symmetrical triangular spacing   Irregular flat spacing   Regular flat spacing

TABLE LXXXIX—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

270 MILES—434.52 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B. & S.)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.848	.0142	15.4	171	-.000008	.001651	.848	.0136	15.4	177	-.000008	.001589	.848	.0132	15.4	182	-.000007	.001543
950 000	.848	.0147	16.1	172	-.000009	.001643	.848	.0142	16.1	178	-.000008	.001581	.848	.0138	16.1	183	-.000008	.001535
900 000	.848	.0154	16.9	173	-.000009	.001635	.848	.0148	16.9	179	-.000008	.001574	.848	.0143	16.9	184	-.000008	.001528
850 000	.848	.0160	17.8	173	-.000009	.001625	.848	.0155	17.8	180	-.000009	.001566	.848	.0150	17.8	185	-.000008	.001520
800 000	.848	.0169	18.8	174	-.000010	.001617	.848	.0162	18.8	181	-.000009	.00155[illegible]	.848	.0158	18.8	186	-.000009	.001512
750 000	.848	.0178	19.9	175	-.000010	.001607	.848	.0171	19.9	182	-.000009	.001548	.848	.0166	19.9	187	-.000009	.001504
700 000	.848	.0188	21.2	176	-.000011	.001597	.848	.0181	21.2	183	-.000010	.001540	.848	.0176	21.2	188	-.000009	.001494
650 000	.848	.0200	22.7	178	-.000011	.001586	.848	.0193	22.7	184	-.000011	.001530	.848	.0187	22.7	189	-.000010	.001484
600 000	.848	.0214	24.4	179	-.000012	.001574	.848	.0206	24.4	185	-.000011	.001517	.848	.0200	24.4	191	-.000011	.001474
550 000	.848	.0230	26.5	181	-.000013	.001561	.848	.0222	26.5	187	-.000012	.001507	.848	.0216	26.5	192	-.000011	.001463
500 000	.848	.0250	29.1	182	-.000014	.001548	.848	.0241	29.1	188	-.000013	.001494	.848	.0235	29.1	194	-.000012	.001453
450 000	.848	.0274	32.1	184	-.000015	.001533	.848	.0264	32.1	190	-.000014	.001481	.848	.0257	32.1	195	-.000013	.001440
400 000	.848	.0304	36.0	186	-.000017	.001517	.848	.0293	36.0	192	-.000015	.001466	.848	.0285	36.0	197	-.000015	.001425
350 000	.848	.0342	41.0	188	-.000018	.001499	.848	.0330	41.0	195	-.000017	.001448	.848	.0321	41.0	200	-.000016	.001410
300 000	.848	.0392	47.7	191	-.000021	.001479	.848	.0379	47.7	197	-.000019	.001430	.848	.0369	47.7	202	-.000018	.001392
250 000	.848	.0462	57.1	194	-.000024	.001456	.848	.0448	57.1	200	-.000023	.001410	.848	.0435	57.1	205	-.000021	.001371
0 000	.847	.0536	67.4	199	-.000028	.001433	.847	.0519	67.4	205	-.000026	.001387	.847	.0506	67.4	210	-.000025	.001351
000	.846	.0663	84.8	203	-.000034	.001407	.847	.0641	84.8	209	-.000031	.001361	.847	.0626	84.8	214	-.000030	.001328
00	.846	.0820	107.	208	-.000041	.001381	.846	.0794	107.	214	-.000038	.001338	.847	.0774	107.	219	-.000036	.001305

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.848	.0129	15.4	187	-.000007	.001504	.848	.0126	15.4	191	-.000007	.001471	.848	.0124	15.4	194	-.000006	.001446
950 000	.848	.0134	16.1	188	-.000007	.001497	.848	.0131	16.1	192	-.000007	.001466	.848	.0129	16.1	195	-.000007	.001438
900 000	.848	.0140	16.9	188	-.000007	.001489	.848	.0137	16.9	192	-.000007	.001458	.848	.0135	16.9	196	-.000007	.001433
850 000	.848	.0147	17.8	189	-.000008	.001484	.848	.0143	17.8	193	-.000007	.001451	.848	.0141	17.8	197	-.000007	.001425
800 000	.848	.0154	18.8	190	-.000008	.001476	.848	.0151	18.8	194	-.000008	.001446	.849	.0148	18.8	198	-.000008	.001417
750 000	.848	.0162	19.9	191	-.000009	.001466	.848	.0159	19.9	195	-.000008	.001438	.849	.0156	19.9	199	-.000008	.001410
700 000	.848	.0172	21.2	192	-.000009	.001458	.849	.0168	21.2	196	-.000009	.001428	.849	.0165	21.2	200	-.000008	.001402
650 000	.848	.0183	22.7	194	-.000010	.001451	.849	.0179	22.7	198	-.000009	.001420	.849	.0176	22.7	201	-.000009	.001394
600 000	.848	.0196	24.4	195	-.000010	.001440	.848	.0191	24.4	199	-.000010	.001410	.848	.0188	24.4	202	-.000009	.001384
550 000	.848	.0211	26.5	197	-.000011	.001430	.848	.0206	26.5	200	-.000010	.001399	.848	.0203	26.5	204	-.000010	.001376
500 000	.848	.0229	29.1	198	-.000012	.001417	.848	.0224	29.1	202	-.000011	.001389	.848	.0220	29.1	205	-.000011	.001366
450 000	.848	.0251	32.1	200	-.000013	.001407	.848	.0246	32.1	204	-.000012	.001379	.848	.0242	32.1	207	-.000012	.001353
400 000	.848	.0278	36.0	202	-.000014	.001392	.848	.0273	36.0	206	-.000013	.001364	.848	.0268	36.0	210	-.000013	.001340
350 000	.848	.0314	41.0	204	-.000015	.001376	.848	.0308	41.0	208	-.000015	.001351	.848	.0303	41.0	212	-.000014	.001328
300 000	.848	.0361	47.7	207	-.000018	.001361	.848	.0353	47.7	211	-.000017	.001333	.848	.0348	47.7	214	-.000016	.001312
250 000	.848	.0425	57.1	210	-.000020	.001340	.848	.0417	57.1	214	-.000020	.001315	.848	.0411	57.1	217	-.000019	.001294
0000	.847	.0495	67.4	214	-.000023	.001323	.847	.0486	67.4	218	-.000023	.001297	.847	.0478	67.4	222	-.000022	.001276
000	.847	.0612	84.8	219	-.000029	.001299	.847	.0[illegible]00	84.8	223	-.000027	.001274	.847	.0591	84.8	226	-.000027	.001253
00	.847	.0758	107.	223	-.000035	.001276	.847	.0744	107.	227	-.000033	.001253	.847	.0732	107.	231	-.000032	.001233

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1000 000	.849	.0122	15.4	197	-.000006	.001420	.849	.0120	15.4	200	-.000006	.001399	.849	.0118	15.4	203	-.000006	.001381
950 000	.849	.0127	16.1	198	-.000006	.001415	.849	.0125	16.1	201	-.000006	.001394	.849	.0123	16.1	204	-.000006	.001376
900 000	.849	.0132	16.9	199	-.000007	.001410	.849	.0130	16.9	202	-.000007	.001389	.849	.0128	16.9	204	-.000006	.001369
850 000	.849	.0138	17.8	200	-.000007	.001402	.849	.0136	17.8	203	-.000007	.001381	.849	.0135	17.8	205	-.000007	.001364
800 000	.849	.0145	18.8	201	-.000007	.001394	.849	.0143	18.8	204	-.000007	.001374	.849	.0141	18.8	206	-.000007	.001356
750 000	.849	.0153	19.9	202	-.000008	.001387	.849	.0151	19.9	205	-.000007	.001369	.849	.0149	19.9	207	-.000007	.001351
700 000	.849	.0162	21.2	203	-.000008	.001379	.849	.0160	21.2	206	-.000008	.001361	.849	.0158	21.2	208	-.000008	.001343
650 000	.849	.0173	22.7	204	-.000009	.001371	.849	.0170	22.7	207	-.000008	.001353	.849	.0168	22.7	210	-.000008	.001335
600 000	.849	.0185	24.4	205	-.000009	.001364	.849	.0182	24.4	208	-.000009	.001343	.849	.0180	24.4	211	-.000009	.001328
550 000	.849	.0199	26.5	207	-.000010	.001353	.849	.0197	26.5	210	-.000009	.001335	.849	.0194	26.5	212	-.000009	.001317
500 000	.849	.0217	29.1	208	-.000010	.001343	.849	.0214	29.1	211	-.000010	.001325	.849	.0211	29.1	214	-.000010	.001307
450 000	.849	.0238	32.1	210	-.000011	.001333	.849	.0235	32.1	213	-.000011	.001315	.849	.0232	32.1	216	-.000011	.001297
400 000	.849	.0264	36.0	213	-.000013	.001320	.849	.0261	36.0	215	-.000012	.001302	.849	.0257	36.0	218	-.000012	.001287
350 000	.849	.0298	41.0	215	-.000014	.001307	.849	.0294	41.0	218	-.000014	.001289	.849	.0290	41.0	220	-.000013	.001274
300 000	.849	.0342	47.7	217	-.000016	.001292	.849	.0338	47.7	220	-.000015	.001274	.849	.0334	47.7	223	-.000015	.001258
250 000	.849	.0404	57.1	220	-.000018	.001274	.849	.0399	57.1	223	-.000018	.001258	.849	.0395	57.1	226	-.000018	.001243
0000	.848	.0470	67.4	225	-.000021	.001256	.848	.0464	67.4	228	-.000021	.001240	.848	.0459	67.4	230	-.000020	.001225
000	.848	.0582	84.8	229	-.000026	.001235	.848	.0575	84.8	232	-.000025	.001220	.848	.0568	84.8	235	-.000025	.001205
00	.847	.0721	107.	234	-.000031	.001215	.848	.0712	107.	237	-.000031	.001199	.848	.0705	107.	239	-.000030	.001187

$A = \cosh\theta = \left(1+\frac{ZY}{2}+\frac{Z^2Y^2}{24}+\frac{Z^3Y^3}{720}+\frac{Z^4Y^4}{40{,}320}+\right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1+\frac{ZY}{6}+\frac{Z^2Y^2}{120}+\frac{Z^3Y^3}{5{,}040}+\frac{Z^4Y^4}{362{,}880}+\right)$

in which Z is the total impedance $(rl+jxl)$ in ohms and Y is the total admittance $(o+jbl\times10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XC—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

270 MILES—434.52 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

9 FEET—2.743 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent circular mils or A. W. G. based upon copper 97% alumin 61%	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0143	14.8	156	−.000009	.001 750
1 510 500	950 000	.853	.0150	15.5	157	−.000009	.001 742
1 431 000	900 000	.853	.0157	16.3	157	−.000010	.001 732
1 351 500	850 000	.853	.0165	17.3	158	−.000010	.001 722
1 272 000	800 000	.853	.0174	18.3	159	−.000011	.001 712
1 192 500	750 000	.853	.0184	19.5	160	−.000011	.001 701
1 113 000	700 000	.853	.0196	20.9	161	−.000012	.001 691
1 033 500	650 000	.853	.0209	22.4	162	−.000013	.001 678
954 000	600 000	.853	.0224	24.3	164	−.000013	.001 665
874 500	550 000	.853	.0243	26.5	165	−.000014	.001 650
795 000	500 000	.853	.0263	29.0	166	−.000015	.001 637
715 500	450 000	.853	.0290	32.4	168	−.000017	.001 619
636 000	400 000	.853	.0322	36.3	170	−.000018	.001 601
556 500	350 000	.853	.0362	40.9	171	−.000021	.001 596
477 000	300 000	.853	.0416	47.7	173	−.000023	.001 573
397 500	250 000	.853	.0490	57.2	177	−.000027	.001 547
336 400	0 000	.852	.0571	67.6	180	−.000031	.001 524
266 800	000	.852	.0700	85.2	186	−.000037	.001 483
0 000	00	.836	.0906	112.	211	−.000047	.001 447

11 FEET—3.353 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0138	14.8	162	−.000008	.001 683
1 510 500	950 000	.853	.0144	15.5	163	−.000009	.001 673
1 431 000	900 000	.853	.0151	16.3	164	−.000009	.001 665
1 351 500	850 000	.853	.0158	17.3	165	−.000009	.001 655
1 272 000	800 000	.853	.0167	18.3	165	−.000010	.001 647
1 192 500	750 000	.853	.0177	19.5	166	−.000010	.001 637
1 113 000	700 000	.853	.0188	20.9	167	−.000011	.001 627
1 033 500	650 000	.853	.0201	22.4	169	−.000012	.001 614
954 000	600 000	.853	.0216	24.3	170	−.000012	.001 604
874 500	550 000	.853	.0234	26.5	171	−.000013	.001 588
795 000	500 000	.853	.0253	29.0	173	−.000014	.001 576
715 500	450 000	.853	.0280	32.4	174	−.000016	.001 563
636 000	400 000	.853	.0311	36.3	176	−.000017	.001 545
556 500	350 000	.853	.0348	40.9	177	−.000019	.001 537
477 000	300 000	.853	.0401	47.7	180	−.000022	.001 517
397 500	250 000	.853	.0474	57.2	183	−.000025	.001 493
336 400	0 000	.853	.0552	67.6	186	−.000029	.001 473
266 800	000	.853	.0676	85.2	192	−.000035	.001 432
0 000	00	.836	.0875	112.	217	−.000044	.001 398

13 FEET—3.962 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0133	14.8	168	−.000008	.001 629
1 510 500	950 000	.853	.0139	15.5	168	−.000008	.001 622
1 431 000	900 000	.853	.0146	16.3	169	−.000008	.001 614
1 351 500	850 000	.853	.0153	17.3	170	−.000009	.001 604
1 272 000	800 000	.853	.0162	18.3	171	−.000009	.001 596
1 192 500	750 000	.853	.0171	19.5	172	−.000010	.001 586
1 113 000	700 000	.853	.0182	20.9	173	−.000010	.001 578
1 033 500	650 000	.853	.0195	22.4	174	−.000011	.001 565
954 000	600 000	.853	.0209	24.3	175	−.000012	.001 555
874 500	550 000	.853	.0227	26.5	176	−.000013	.001 542
795 000	500 000	.853	.0246	29.0	178	−.000013	.001 529
715 500	450 000	.853	.0272	32.4	179	−.000015	.001 514
636 000	400 000	.853	.0301	36.3	181	−.000016	.001 499
556 500	350 000	.853	.0338	40.9	182	−.000018	.001 493
477 000	300 000	.853	.0390	47.7	185	−.000021	.001 475
397 500	250 000	.853	.0460	57.2	188	−.000024	.001 452
336 400	0 000	.853	.0537	67.6	191	−.000028	.001 432
266 800	000	.853	.0659	85.2	195	−.000033	.001 396
0 000	00	.837	.0853	112.	222	−.000042	.001 363

15 FEET—4.572 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0130	14.8	172	−.000007	.001 586
1 510 500	950 000	.853	.0136	15.5	173	−.000008	.001 578
1 431 000	900 000	.853	.0142	16.3	174	−.000008	.001 570
1 351 500	850 000	.853	.0149	17.3	174	−.000008	.001 563
1 272 000	800 000	.853	.0158	18.3	175	−.000009	.001 555
1 192 500	750 000	.853	.0167	19.5	176	−.000009	.001 545
1 113 000	700 000	.853	.0178	20.9	177	−.000010	.001 537
1 033 500	650 000	.853	.0190	22.4	178	−.000010	.001 527
954 000	600 000	.853	.0204	24.3	180	−.000011	.001 517
874 500	550 000	.853	.0221	26.5	181	−.000012	.001 504
795 000	500 000	.853	.0239	29.0	182	−.000013	.001 491
715 500	450 000	.853	.0265	32.4	184	−.000014	.001 478
636 000	400 000	.853	.0294	36.3	186	−.000015	.001 463
556 500	350 000	.853	.0330	40.9	187	−.000017	.001 457
477 000	300 000	.853	.0381	47.7	189	−.000020	.001 440
397 500	250 000	.853	.0449	57.2	193	−.000023	.001 416
336 400	0 000	.853	.0524	67.6	196	−.000026	.001 398
266 800	000	.853	.0643	85.2	201	−.000031	.001 363
0 000	00	.837	.0834	112.	226	−.000040	.001 332

17 FEET—5.182 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0127	14.8	176	−.000007	.001 550
1 510 500	950 000	.853	.0133	15.5	177	−.000007	.001 545
1 431 000	900 000	.853	.0139	16.3	177	−.000008	.001 537
1 351 500	850 000	.853	.0146	17.3	178	−.000008	.001 529
1 272 000	800 000	.853	.0154	18.3	179	−.000008	.001 522
1 192 500	750 000	.853	.0163	19.5	180	−.000009	.001 511
1 113 000	700 000	.853	.0174	20.9	181	−.000009	.001 504
1 033 500	650 000	.853	.0186	22.4	182	−.000010	.001 493
954 000	600 000	.853	.0200	24.3	183	−.000011	.001 483
874 500	550 000	.853	.0217	26.5	185	−.000011	.001 473
795 000	500 000	.853	.0234	29.0	186	−.000012	.001 460
715 500	450 000	.853	.0260	32.4	188	−.000013	.001 447
636 000	400 000	.853	.0288	36.3	190	−.000015	.001 434
556 500	350 000	.853	.0323	40.9	191	−.000017	.001 427
477 000	300 000	.853	.0372	47.7	193	−.000019	.001 409
397 500	250 000	.853	.0440	57.2	196	−.000022	.001 388
336 400	0 000	.853	.0514	67.6	200	−.000025	.001 370
266 800	000	.853	.0631	85.2	205	−.000030	.001 337
0 000	00	.838	.0819	112.	230	−.000039	.001 308

19 FEET—5.791 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0125	14.8	180	−.000007	.001 522
1 510 500	950 000	.853	.0130	15.5	180	−.000007	.001 514
1 431 000	900 000	.853	.0136	16.3	181	−.000007	.001 506
1 351 500	850 000	.853	.0143	17.3	182	−.000008	.001 499
1 272 000	800 000	.853	.0151	18.3	183	−.000008	.001 491
1 192 500	750 000	.853	.0160	19.5	183	−.000009	.001 483
1 113 000	700 000	.853	.0171	20.9	184	−.000009	.001 475
1 033 500	650 000	.853	.0182	22.4	186	−.000010	.001 465
954 000	600 000	.853	.0196	24.3	187	−.000010	.001 455
874 500	550 000	.853	.0212	26.5	188	−.000011	.001 445
795 000	500 000	.853	.0230	29.0	190	−.000012	.001 434
715 500	450 000	.853	.0255	32.4	191	−.000013	.001 422
636 000	400 000	.853	.0283	36.3	193	−.000014	.001 409
556 500	350 000	.853	.0318	40.9	194	−.000016	.001 401
477 000	300 000	.853	.0366	47.7	197	−.000018	.001 386
397 500	250 000	.853	.0433	57.2	200	−.000021	.001 365
336 400	0 000	.853	.0505	67.6	203	−.000024	.001 347
266 800	000	.853	.0620	85.2	209	−.000029	.001 314
0 000	00	.838	.0804	112.	234	−.000037	.001 285

21 FEET—6.401 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0123	14.8	183	−.000007	.001 496
1 510 500	950 000	.853	.0128	15.5	183	−.000007	.001 488
1 431 000	900 000	.853	.0134	16.3	184	−.000007	.001 481
1 351 500	850 000	.853	.0141	17.3	185	−.000007	.001 473
1 272 000	800 000	.853	.0149	18.3	186	−.000008	.001 468
1 192 500	750 000	.853	.0158	19.5	187	−.000008	.001 457
1 113 000	700 000	.853	.0168	20.9	187	−.000009	.001 450
1 033 500	650 000	.853	.0179	22.4	188	−.000009	.001 440
954 000	600 000	.853	.0193	24.3	190	−.000010	.001 432
874 500	550 000	.853	.0209	26.5	191	−.000011	.001 422
795 000	500 000	.853	.0226	29.0	193	−.000011	.001 409
715 500	450 000	.853	.0251	32.4	194	−.000013	.001 398
636 000	400 000	.853	.0279	36.3	196	−.000014	.001 386
556 500	350 000	.853	.0313	40.9	197	−.000015	.001 381
477 000	300 000	.853	.0360	47.7	200	−.000018	.001 363
397 500	250 000	.853	.0426	57.2	203	−.000021	.001 345
336 400	0 000	.853	.0497	67.6	206	−.000024	.001 327
266 800	000	.853	.0611	85.2	212	−.000028	.001 293
0 000	00	.838	.0793	112.	237	−.000036	.001 267

23 FEET—7.010 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0120	14.8	185	−.000006	.001 470
1 510 500	950 000	.853	.0126	15.5	186	−.000007	.001 465
1 431 000	900 000	.853	.0132	16.3	187	−.000007	.001 457
1 351 500	850 000	.853	.0139	17.3	187	−.000007	.001 452
1 272 000	800 000	.853	.0147	18.3	188	−.000008	.001 445
1 192 500	750 000	.853	.0155	19.5	190	−.000008	.001 437
1 113 000	700 000	.853	.0165	20.9	190	−.000008	.001 429
1 033 500	650 000	.853	.0177	22.4	191	−.000009	.001 419
954 000	600 000	.853	.0190	24.3	193	−.000010	.001 411
874 500	550 000	.853	.0206	26.5	194	−.000010	.001 401
795 000	500 000	.854	.0223	29.0	196	−.000011	.001 388
715 500	450 000	.854	.0247	32.4	197	−.000012	.001 378
636 000	400 000	.853	.0274	36.3	199	−.000013	.001 365
556 500	350 000	.853	.0308	40.9	200	−.000015	.001 360
477 000	300 000	.853	.0355	47.7	203	−.000017	.001 345
397 500	250 000	.853	.0420	57.2	206	−.000020	.001 324
336 400	0 000	.853	.0491	67.6	209	−.000023	.001 309
266 800	000	.853	.0603	85.2	215	−.000028	.001 278
0 000	00	.839	.0782	112.	239	−.000035	.001 249

25 FEET—7.620 METERS

Circular mils or A. W. G. (B & S)	Copper equivalent	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 590 000	1 000 000	.853	.0119	14.8	188	−.000006	.001 457
1 510 500	950 000	.853	.0124	15.5	188	−.000006	.001 445
1 431 000	900 000	.853	.0130	16.3	189	−.000007	.001 437
1 351 500	850 000	.853	.0137	17.3	190	−.000007	.001 432
1 272 000	800 000	.853	.0145	18.3	191	−.000007	.001 424
1 192 500	750 000	.853	.0153	19.5	192	−.000008	.001 416
1 113 000	700 000	.853	.0163	20.9	193	−.000008	.001 409
1 033 500	650 000	.853	.0174	22.4	194	−.000009	.001 401
954 000	600 000	.854	.0187	24.3	195	−.000009	.001 391
874 500	550 000	.854	.0203	26.5	197	−.000010	.001 381
795 000	500 000	.854	.0220	29.0	198	−.000011	.001 370
715 500	450 000	.854	.0244	32.4	200	−.000012	.001 360
636 000	400 000	.853	.0271	36.3	202	−.000013	.001 347
556 500	350 000	.853	.0304	40.9	203	−.000015	.001 342
477 000	300 000	.853	.0351	47.7	205	−.000017	.001 327
397 500	250 000	.853	.0415	57.2	209	−.000019	.001 309
336 400	0 000	.853	.0484	67.6	212	−.000022	.001 291
266 800	000	.853	.0596	85.2	217	−.000027	.001 262
0 000	00	.839	.0774	112.	242	−.000034	.001 236

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

TABLE XCI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

280 MILES—450.62 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

9 FEET—2.743 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.836	.0152	15.9	176	-.000 009	.001 702
950 000	.836	.0158	16.6	177	-.000 010	.001 694
900 000	.836	.0164	17.4	178	-.000 010	.001 686
850 000	.836	.0172	18.3	179	-.000 010	.001 676
800 000	.836	.0180	19.3	180	-.000 011	.001 668
750 000	.836	.0190	20.4	181	-.000 011	.001 657
700 000	.837	.0201	21.8	182	-.000 012	.001 647
650 000	.837	.0214	23.3	183	-.000 013	.001 636
600 000	.836	.0229	25.1	185	-.000 013	.001 623
550 000	.836	.0246	27.3	186	-.000 014	.001 610
500 000	.836	.0268	29.9	188	-.000 015	.001 596
450 000	.836	.0293	33.0	190	-.000 017	.001 581
400 000	.836	.0325	37.0	192	-.000 018	.001 565
350 000	.836	.0366	42.2	194	-.000 020	.001 546
300 000	.836	.0420	49.1	197	-.000 023	.001 525
250 000	.836	.0495	58.7	200	-.000 027	.001 501
0 000	.835	.0574	69.3	205	-.000 031	.001 477
000	.835	.0710	87.2	210	-.000 037	.001 451
00	.834	.0878	110.	215	-.000 045	.001 425

11 FEET—3.353 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.837	.0146	15.9	183	-.000 009	.001 639
950 000	.837	.0152	16.6	184	-.000 009	.001 631
900 000	.837	.0158	17.4	184	-.000 009	.001 623
850 000	.837	.0166	18.3	185	-.000 010	.001 615
800 000	.837	.0174	19.3	186	-.000 010	.001 607
750 000	.837	.0183	20.4	187	-.000 011	.001 596
700 000	.837	.0194	21.8	188	-.000 011	.001 588
650 000	.837	.0206	23.3	190	-.000 012	.001 578
600 000	.837	.0221	25.1	191	-.000 012	.001 565
550 000	.837	.0238	27.3	193	-.000 013	.001 554
500 000	.837	.0258	29.9	194	-.000 014	.001 541
450 000	.837	.0283	33.0	196	-.000 016	.001 528
400 000	.837	.0314	37.0	198	-.000 017	.001 512
350 000	.837	.0353	42.2	201	-.000 019	.001 493
300 000	.837	.0406	49.1	203	-.000 022	.001 475
250 000	.837	.0479	58.7	207	-.000 025	.001 454
0 000	.835	.0556	69.3	212	-.000 029	.001 430
000	.835	.0687	87.2	216	-.000 035	.001 403
00	.835	.0850	110.	221	-.000 042	.001 380

13 FEET—3.962 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.837	.0142	15.9	188	-.000 008	.001 591
950 000	.837	.0147	16.6	189	-.000 008	.001 583
900 000	.837	.0154	17.4	190	-.000 009	.001 575
850 000	.837	.0161	18.3	191	-.000 009	.001 567
800 000	.837	.0169	19.3	192	-.000 010	.001 559
750 000	.837	.0178	20.4	193	-.000 010	.001 551
700 000	.837	.0188	21.8	194	-.000 010	.001 541
650 000	.837	.0200	23.3	195	-.000 011	.001 530
600 000	.837	.0214	25.1	197	-.000 012	.001 520
550 000	.837	.0231	27.3	198	-.000 013	.001 509
500 000	.837	.0251	29.9	200	-.000 014	.001 499
450 000	.837	.0275	33.0	201	-.000 015	.001 485
400 000	.837	.0305	37.0	204	-.000 016	.001 470
350 000	.837	.0344	42.2	206	-.000 018	.001 454
300 000	.837	.0395	49.1	209	-.000 021	.001 435
250 000	.837	.0466	58.7	212	-.000 024	.001 414
0 000	.836	.0541	69.3	217	-.000 027	.001 393
000	.836	.0670	87.2	221	-.000 033	.001 369
00	.835	.0829	110.	226	-.000 040	.001 345

15 FEET—4.572 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.837	.0138	15.9	192	-.000 008	.001 551
950 000	.837	.0144	16.6	194	-.000 008	.001 544
900 000	.837	.0150	17.4	194	-.000 008	.001 536
850 000	.837	.0157	18.3	195	-.000 009	.001 530
800 000	.837	.0165	19.3	196	-.000 009	.001 522
750 000	.837	.0173	20.4	197	-.000 009	.001 512
700 000	.837	.0184	21.8	198	-.000 010	.001 504
650 000	.837	.0196	23.3	200	-.000 011	.001 496
600 000	.837	.0209	25.1	201	-.000 011	.001 485
550 000	.837	.0226	27.3	203	-.000 012	.001 475
500 000	.837	.0245	29.9	204	-.000 013	.001 462
450 000	.837	.0269	33.0	206	-.000 014	.001 451
400 000	.837	.0298	37.0	208	-.000 015	.001 435
350 000	.837	.0336	42.2	211	-.000 017	.001 419
300 000	.837	.0386	49.1	213	-.000 020	.001 403
250 000	.837	.0456	58.7	216	-.000 023	.001 382
0 000	.836	.0530	69.3	221	-.000 026	.001 364
000	.836	.0656	87.2	226	-.000 032	.001 340
00	.836	.0812	110.	231	-.000 039	.001 316

17 FEET—5.182 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.837	.0135	15.9	197	-.000 007	.001 517
950 000	.837	.0141	16.6	198	-.000 008	.001 512
900 000	.837	.0147	17.4	198	-.000 008	.001 504
850 000	.837	.0153	18.3	199	-.000 008	.001 496
800 000	.837	.0161	19.3	200	-.000 009	.001 491
750 000	.837	.0170	20.4	201	-.000 009	.001 483
700 000	.837	.0180	21.8	202	-.000 010	.001 472
650 000	.837	.0192	23.3	204	-.000 010	.001 464
600 000	.837	.0205	25.1	205	-.000 011	.001 454
550 000	.837	.0221	27.3	207	-.000 012	.001 443
500 000	.837	.0240	29.9	208	-.000 012	.001 433
450 000	.837	.0264	33.0	210	-.000 014	.001 422
400 000	.837	.0292	37.0	212	-.000 015	.001 406
350 000	.837	.0330	42.2	215	-.000 017	.001 393
300 000	.837	.0378	49.1	217	-.000 019	.001 374
250 000	.837	.0447	58.7	221	-.000 022	.001 356
0 000	.836	.0520	69.3	225	-.000 025	.001 337
000	.836	.0643	87.2	230	-.000 031	.001 314
00	.836	.0797	110.	235	-.000 037	.001 292

19 FEET—5.791 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.837	.0133	15.9	200	-.000 007	.001 491
950 000	.837	.0138	16.6	201	-.000 007	.001 483
900 000	.837	.0144	17.4	202	-.000 008	.001 477
850 000	.837	.0151	18.3	203	-.000 008	.001 470
800 000	.837	.0158	19.3	204	-.000 008	.001 462
750 000	.837	.0167	20.4	205	-.000 009	.001 454
700 000	.837	.0177	21.8	206	-.000 009	.001 446
650 000	.837	.0188	23.3	207	-.000 010	.001 438
600 000	.837	.0201	25.1	209	-.000 010	.001 427
550 000	.837	.0217	27.3	210	-.000 011	.001 419
500 000	.837	.0236	29.9	212	-.000 012	.001 409
450 000	.837	.0259	33.0	213	-.000 013	.001 396
400 000	.837	.0287	37.0	216	-.000 014	.001 382
350 000	.837	.0324	42.2	218	-.000 016	.001 369
300 000	.837	.0373	49.1	221	-.000 018	.001 353
250 000	.837	.0440	58.7	224	-.000 021	.001 335
0 000	.836	.0511	69.3	229	-.000 024	.001 316
000	.836	.0633	87.2	233	-.000 030	.001 292
00	.836	.0784	110.	238	-.000 036	.001 271

21 FEET—6.401 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.838	.0130	15.9	203	-.000 007	.001 464
950 000	.838	.0136	16.6	204	-.000 007	.001 459
900 000	.838	.0142	17.4	205	-.000 007	.001 454
850 000	.838	.0148	18.3	206	-.000 008	.001 446
800 000	.838	.0156	19.3	207	-.000 008	.001 438
750 000	.838	.0164	20.4	208	-.000 008	.001 430
700 000	.838	.0174	21.8	209	-.000 009	.001 422
650 000	.838	.0185	23.3	210	-.000 009	.001 414
600 000	.838	.0198	25.1	212	-.000 010	.001 406
550 000	.838	.0214	27.3	213	-.000 011	.001 396
500 000	.838	.0232	29.9	215	-.000 012	.001 385
450 000	.838	.0255	33.0	217	-.000 013	.001 374
400 000	.837	.0283	37.0	219	-.000 014	.001 361
350 000	.837	.0319	42.2	221	-.000 016	.001 348
300 000	.837	.0367	49.1	224	-.000 018	.001 332
250 000	.837	.0433	58.7	227	-.000 021	.001 314
0 000	.836	.0503	69.3	232	-.000 024	.001 295
000	.836	.0624	87.2	236	-.000 029	.001 274
00	.836	.0772	110.	241	-.000 035	.001 253

23 FEET—7.010 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.838	.0128	15.9	206	-.000 007	.001 443
950 000	.838	.0134	16.6	207	-.000 007	.001 438
900 000	.838	.0140	17.4	208	-.000 007	.001 433
850 000	.838	.0146	18.3	209	-.000 008	.001 425
800 000	.838	.0153	19.3	210	-.000 008	.001 417
750 000	.838	.0162	20.4	211	-.000 008	.001 411
700 000	.838	.0171	21.8	212	-.000 009	.001 403
650 000	.838	.0183	23.3	213	-.000 009	.001 396
600 000	.838	.0195	25.1	215	-.000 010	.001 385
550 000	.838	.0211	27.3	216	-.000 010	.001 377
500 000	.838	.0229	29.9	218	-.000 011	.001 366
450 000	.838	.0251	33.0	220	-.000 012	.001 356
400 000	.837	.0279	37.0	222	-.000 014	.001 343
350 000	.837	.0315	42.2	224	-.000 015	.001 329
300 000	.837	.0362	49.1	227	-.000 017	.001 314
250 000	.837	.0428	58.7	230	-.000 020	.001 298
0 000	.836	.0497	69.3	235	-.000 023	.001 279
000	.836	.0616	87.2	239	-.000 028	.001 258
00	.836	.0763	110.	244	-.000 034	.001 237

25 FEET—7.620 METERS

Circular mils or A. W. G. (B & S)	A a_1	A ja_2	B b_1	B jb_2	C c_1	C jc_2
1 000 000	.838	.0127	15.9	209	-.000 007	.001 425
950 000	.838	.0132	16.6	210	-.000 007	.001 419
900 000	.838	.0138	17.4	211	-.000 007	.001 411
850 000	.838	.0144	18.3	212	-.000 007	.001 406
800 000	.838	.0151	19.3	213	-.000 008	.001 398
750 000	.838	.0160	20.4	214	-.000 008	.001 393
700 000	.838	.0169	21.8	215	-.000 008	.001 385
650 000	.838	.0180	23.3	216	-.000 009	.001 377
600 000	.838	.0193	25.1	217	-.000 010	.001 369
550 000	.838	.0208	27.3	219	-.000 010	.001 359
500 000	.838	.0226	29.9	220	-.000 011	.001 348
450 000	.838	.0248	33.0	222	-.000 012	.001 337
400 000	.838	.0276	37.0	225	-.000 013	.001 327
350 000	.838	.0311	42.2	227	-.000 015	.001 314
300 000	.838	.0357	49.1	230	-.000 017	.001 298
250 000	.838	.0423	58.7	233	-.000 020	.001 282
0 000	.837	.0491	69.3	238	-.000 022	.001 263
000	.837	.0608	87.2	242	-.000 027	.001 242
00	.836	.0755	110.	247	-.000 033	.001 224

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

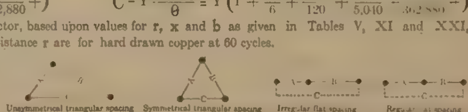


TABLE XCII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

280 MILES—450.62 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A W G (B. & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.842	.0154	15.2	161	-.000 010	.001 807	.842	.0148	15.2	168	-.000 009	.001 738	.842	.0143	15.2	173	-.000 009	.001 683
1 510 500	950 000	.842	.0160	15.9	162	-.000 010	.001 799	.842	.0154	15.9	168	-.000 010	.001 728	.842	.0149	15.9	174	-.000 009	.001 675
1 431 000	900 000	.842	.0168	16.8	163	-.000 011	.001 789	.842	.0161	16.8	169	-.000 010	.001 720	.842	.0157	16.8	175	-.000 009	.001 667
1 351 500	850 000	.842	.0176	17.8	163	-.000 011	.001 778	.842	.0170	17.8	170	-.000 010	.001 709	.842	.0164	17.8	175	-.000 010	.001 656
1 272 000	800 000	.842	.0186	18.8	164	-.000 012	.001 768	.842	.0179	18.8	171	-.000 011	.001 701	.842	.0173	18.8	176	-.000 010	.001 648
1 192 500	750 000	.842	.0197	20.1	166	-.000 012	.001 757	.842	.0189	20.1	172	-.000 012	.001 691	.842	.0184	20.1	177	-.000 011	.001 638
1 113 000	700 000	.842	.0209	21.5	166	-.000 013	.001 746	.842	.0201	21.5	173	-.000 012	.001 680	.842	.0195	21.5	178	-.000 011	.001 630
1 033 500	650 000	.842	.0224	23.1	168	-.000 014	.001 733	.842	.0215	23.1	174	-.000 013	.001 667	.842	.0209	23.1	179	-.000 012	.001 617
954 000	600 000	.842	.0240	25.0	169	-.000 015	.001 720	.842	.0231	25.0	175	-.000 014	.001 656	.842	.0224	25.0	181	-.000 013	.001 606
874 500	550 000	.842	.0260	27.3	170	-.000 016	.001 704	.842	.0250	27.3	177	-.000 015	.001 640	.843	.0243	27.3	182	-.000 014	.001 593
795 000	500 000	.842	.0281	29.8	172	-.000 017	.001 691	.842	.0271	29.8	178	-.000 016	.001 627	.843	.0263	29.8	184	-.000 015	.001 579
715 500	450 000	.842	.0311	33.3	173	-.000 019	.001 672	.842	.0300	33.3	180	-.000 017	.001 614	.843	.0291	33.3	185	-.000 016	.001 564
636 000	400 000	.842	.0345	37.3	176	-.000 021	.001 654	.842	.0333	37.3	182	-.000 019	.001 595	.843	.0323	37.3	187	-.000 018	.001 548
556 500	350 000	.842	.0387	42.1	177	-.000 023	.001 648	.843	.0373	42.1	183	-.000 021	.001 587	.843	.0363	42.1	188	-.000 020	.001 542
477 000	300 000	.842	.0445	49.1	179	-.000 026	.001 624	.842	.0429	49.1	186	-.000 024	.001 566	.842	.0418	49.1	191	-.000 023	.001 524
397 500	250 000	.842	.0525	58.8	183	-.000 030	.001 598	.842	.0507	58.8	189	-.000 028	.001 542	.842	.0493	58.8	195	-.000 027	.001 500
336 400	0 000	.842	.0612	69.6	186	-.000 035	.001 574	.842	.0592	69.6	192	-.000 032	.001 521	.842	.0575	69.6	198	-.000 031	.001 479
266 800	000	.841	.0750	87.6	192	-.000 041	.001 532	.842	.0724	87.6	198	-.000 039	.001 479	.842	.0706	87.6	204	-.000 037	.001 442
0 000	00	.824	.0970	115.	218	-.000 053	.001 494	.824	.0937	115.	224	-.000 049	.001 444	.825	.0913	115.	229	-.000 047	.001 407

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.842	.0139	15.2	178	-.000 008	.001 638	.842	.0136	15.2	182	-.000 008	.001 601	.842	.0134	15.2	185	-.000 008	.001 571
1 510 500	950 000	.842	.0145	15.9	178	-.000 009	.001 630	.842	.0142	15.9	182	-.000 008	.001 595	.842	.0139	15.9	186	-.000 008	.001 564
1 431 000	900 000	.842	.0152	16.8	179	-.000 009	.001 622	.842	.0149	16.8	183	-.000 009	.001 587	.842	.0146	16.8	187	-.000 008	.001 556
1 351 500	850 000	.842	.0160	17.8	180	-.000 009	.001 614	.842	.0157	17.8	184	-.000 009	.001 579	.842	.0154	17.8	188	-.000 009	.001 548
1 272 000	800 000	.842	.0169	18.8	181	-.000 010	.001 606	.842	.0165	18.8	185	-.000 009	.001 571	.842	.0162	18.8	189	-.000 009	.001 540
1 192 500	750 000	.842	.0179	20.1	182	-.000 010	.001 595	.842	.0175	20.1	186	-.000 010	.001 561	.842	.0172	20.1	189	-.000 009	.001 532
1 113 000	700 000	.842	.0190	21.5	183	-.000 011	.001 587	.842	.0186	21.5	187	-.000 010	.001 553	.842	.0183	21.5	190	-.000 010	.001 524
1 033 500	650 000	.842	.0203	23.1	184	-.000 012	.001 577	.843	.0199	23.1	188	-.000 011	.001 542	.843	.0195	23.1	192	-.000 011	.001 513
954 000	600 000	.842	.0218	25.0	185	-.000 012	.001 566	.843	.0214	25.0	189	-.000 012	.001 532	.843	.0210	25.0	193	-.000 011	.001 503
874 500	550 000	.843	.0237	27.3	187	-.000 013	.001 553	.843	.0232	27.3	191	-.000 013	.001 521	.843	.0228	27.3	194	-.000 012	.001 492
795 000	500 000	.843	.0256	29.8	188	-.000 014	.001 540	.843	.0251	29.8	192	-.000 014	.001 508	.843	.0247	29.8	196	-.000 013	.001 481
715 500	450 000	.843	.0284	33.3	190	-.000 016	.001 526	.843	.0278	33.3	194	-.000 015	.001 495	.843	.0273	33.3	198	-.000 014	.001 468
636 000	400 000	.843	.0315	37.3	192	-.000 017	.001 511	.843	.0309	37.3	196	-.000 016	.001 481	.843	.0303	37.3	199	-.000 016	.001 455
556 500	350 000	.843	.0354	42.1	193	-.000 019	.001 505	.843	.0346	42.1	197	-.000 018	.001 473	.843	.0340	42.1	200	-.000 018	.001 447
477 000	300 000	.842	.0408	49.1	196	-.000 022	.001 487	.842	.0399	49.1	200	-.000 021	.001 455	.842	.0392	49.1	203	-.000 020	.001 431
397 500	250 000	.842	.0481	58.8	199	-.000 025	.001 463	.842	.0471	58.8	203	-.000 024	.001 434	.842	.0463	58.8	207	-.000 024	.001 410
336 400	0 000	.842	.0562	69.6	202	-.000 029	.001 444	.842	.0551	69.6	206	-.000 028	.001 415	.842	.0541	69.6	210	-.000 027	.001 391
266 800	000	.842	.0689	87.6	208	-.000 035	.001 407	.842	.0676	87.6	212	-.000 034	.001 381	.842	.0664	87.6	216	-.000 032	.001 357
0 000	00	.825	.0893	115.	234	-.000 045	.001 375	.826	.0876	115.	238	-.000 043	.001 350	.826	.0861	115.	241	-.000 041	.001 326

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.842	.0131	15.2	189	-.000 007	.001 545	.842	.0129	15.2	191	-.000 007	.001 518	.842	.0127	15.2	194	-.000 007	.001 500
1 510 500	950 000	.842	.0137	15.9	189	-.000 008	.001 537	.842	.0135	15.9	192	-.000 007	.001 513	.842	.0133	15.9	195	-.000 007	.001 492
1 431 000	900 000	.842	.0144	16.8	190	-.000 008	.001 529	.842	.0141	16.8	193	-.000 008	.001 505	.843	.0139	16.8	195	-.000 007	.001 484
1 351 500	850 000	.842	.0151	17.8	191	-.000 008	.001 521	.842	.0149	17.8	194	-.000 008	.001 500	.843	.0147	17.8	196	-.000 008	.001 479
1 272 000	800 000	.842	.0159	18.8	192	-.000 009	.001 516	.842	.0157	18.8	195	-.000 008	.001 492	.843	.0155	18.8	197	-.000 008	.001 471
1 192 500	750 000	.842	.0169	20.1	193	-.000 009	.001 505	.842	.0166	20.1	196	-.000 009	.001 484	.843	.0164	20.1	198	-.000 009	.001 463
1 113 000	700 000	.843	.0180	21.5	194	-.000 010	.001 497	.843	.0177	21.5	197	-.000 009	.001 476	.843	.0174	21.5	199	-.000 009	.001 455
1 033 500	650 000	.843	.0192	23.1	195	-.000 010	.001 487	.843	.0189	23.1	198	-.000 010	.001 465	.843	.0187	23.1	201	-.000 010	.001 447
954 000	600 000	.843	.0206	25.0	196	-.000 011	.001 479	.843	.0203	25.0	199	-.000 011	.001 458	.843	.0200	25.0	202	-.000 010	.001 436
874 500	550 000	.843	.0224	27.3	197	-.000 012	.001 468	.843	.0221	27.3	200	-.000 011	.001 447	.843	.0217	27.3	203	-.000 011	.001 426
795 000	500 000	.843	.0242	29.8	199	-.000 013	.001 455	.843	.0239	29.8	202	-.000 012	.001 434	.843	.0236	29.8	205	-.000 012	.001 415
715 500	450 000	.843	.0269	33.3	201	-.000 014	.001 444	.843	.0265	33.3	204	-.000 014	.001 423	.843	.0261	33.3	206	-.000 013	.001 405
636 000	400 000	.843	.0298	37.3	203	-.000 015	.001 431	.843	.0294	37.3	206	-.000 015	.001 410	.843	.0290	37.3	208	-.000 015	.001 391
556 500	350 000	.843	.0335	42.1	204	-.000 017	.001 426	.843	.0330	42.1	206	-.000 017	.001 405	.843	.0326	42.1	209	-.000 016	.001 386
477 000	300 000	.842	.0386	49.1	206	-.000 020	.001 407	.842	.0381	49.1	209	-.000 019	.001 389	.843	.0376	49.1	212	-.000 019	.001 370
397 500	250 000	.842	.0456	58.8	210	-.000 023	.001 389	.842	.0450	58.8	213	-.000 022	.001 367	.842	.0445	58.8	215	-.000 022	.001 352
336 400	0 000	.842	.0533	69.6	213	-.000 026	.001 370	.842	.0526	69.6	216	-.000 026	.001 352	.842	.0518	69.6	219	-.000 025	.001 333
266 800	000	.842	.0654	87.6	219	-.000 031	.001 336	.842	.0646	87.6	222	-.000 031	.001 320	.842	.0638	87.6	224	-.000 030	.001 304
0 000	00	.826	.0849	115.	245	-.000 040	.001 308	.827	.0837	115.	247	-.000 039	.001 289	.827	.0828	115.	250	-.000 038	.001 276

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XCIII—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

290 MILES—466.71 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.825	.0162	16.3	182	-.000010	.001 758	.825	.0156	16.3	189	-.000 010	.001 693	.825	.0151	16.3	194	-.000 009	.001 643
950 000	.825	.0168	17.0	183	-.000011	.001 750	.825	.0162	17.0	190	-.000010	.001 684	.825	.0157	17.0	195	-.000 009	.001 635
900 000	.825	.0176	17.8	184	-.000011	.001 742	.825	.0169	17.8	190	-.000010	.001 676	.825	.0164	17.8	196	-.000 010	.001 627
850 000	.825	.0184	18.8	185	-.000012	.001 731	.825	.0177	18.8	192	-.000011	.001 668	.825	.0172	18.8	197	-.000010	.001 619
800 000	.825	.0193	19.8	186	-.000012	.001 723	.825	.0186	19.8	192	-.000011	.001 660	.825	.0180	19.8	198	-.000011	.001 611
750 000	.825	.0203	21.0	187	-.000013	.001 712	.825	.0196	21.0	193	-.000012	.001 649	.825	.0190	21.0	199	-.000011	.001 603
700 000	.825	.0215	22.4	188	-.000013	.001 701	.825	.0207	22.4	195	-.000 012	.001 641	.826	.0201	22.4	200	-.000012	.001 592
650 000	.825	.0229	23.9	189	-.000014	.001 690	.825	.0220	23.9	196	-.000 013	.001 630	.826	.0214	23.9	201	-.000012	.001 581
600 000	.825	.0244	25.8	191	-.000015	.001 676	.825	.0236	25.8	198	-.000 014	.001 616	.825	.0229	25.8	203	-.000013	.001 570
550 000	.825	.0263	28.0	192	-.000016	.001 663	.825	.0254	28.0	199	-.000 015	.001 605	.825	.0247	28.0	204	-.000014	.001 559
500 000	.825	.0286	30.7	194	-.000017	.001 649	.825	.0276	30.7	201	-.000 016	.001 592	.825	.0268	30.7	206	-.000015	.001 548
450 000	.825	.0313	33.9	196	-.000019	.001 633	.825	.0303	33.9	202	-.000017	.001 578	.825	.0294	33.9	208	-.000016	.001 534
400 000	.825	.0347	38.0	198	-.000020	.001 616	.825	.0336	38.0	205	-.000019	.001 562	.825	.0326	38.0	210	-.000 018	.001 518
350 000	.825	.0391	43.3	201	-.000023	.001 597	.825	.0377	43.3	207	-.000021	.001 542	.825	.0367	43.3	213	-.000020	.001 502
300 000	.825	.0448	50.4	203	-.000026	.001 575	.825	.0434	50.4	210	-.000024	.001 523	.825	.0422	50.4	216	-.000023	.001 482
250 000	.825	.0529	60.3	207	-.000030	.001 551	.825	.0512	60.3	214	-.000028	.001 502	.825	.0498	60.3	219	-.000026	.001 461
0 000	.824	.0614	71.1	212	-.000034	.001 526	.824	.0594	71.1	219	-.000032	.001 477	.824	.0578	71.1	224	-.000030	.001 439
000	.823	.0759	89.5	217	-.000041	.001 499	.824	.0734	89.5	223	-.000039	.001 450	.824	.0715	89.5	229	-.000037	.001 414
00	.823	.0938	113.	222	-.000050	.001 471	.823	.0908	113.	229	-.000047	.001 425	.823	.0886	113.	234	-.000 045	.001 390

	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.826	.0148	16.3	199	-.000009	.001 603	.826	.0144	16.3	203	-.000 008	.001 567	.826	.0142	16.3	207	-.000008	.001 540
950 000	.826	.0153	17.0	200	-.000009	.001 594	.826	.0150	17.0	204	-.000 009	.001 562	.826	.0147	17.0	208	-.000008	.001 532
900 000	.826	.0160	17.8	201	-.000009	.001 586	.826	0157	17.8	205	-.000 009	.001 553	.826	.0154	17.8	208	-.000009	.001 526
850 000	.826	.0168	18.8	202	-.000010	.001 581	.826	.0164	18.8	206	-.000 009	.001 545	.826	.0161	18.8	210	-.000009	.001 518
800 000	.826	.0176	19.8	203	-.000010	.001 572	.826	.0172	19.8	207	-.000010	.001 540	.826	.0169	19.8	211	-.000009	.001 510
750 000	.826	.0185	21.0	204	-.000011	.001 562	.826	.0182	21.0	208	-.000010	.001 532	.826	.0178	21.0	212	-.000010	.001 502
700 000	.826	.0196	22.4	205	-.000011	.001 553	.826	.0192	22.4	209	-.000011	.001 521	.826	.0189	22.4	213	-.000010	.001 493
650 000	.826	.0209	23.9	206	-.000012	.001 545	.826	.0205	23.9	210	-.000011	.001 512	.826	.0201	23.9	214	-.000011	.001 485
600 000	.826	.0224	25.8	208	-.000012	.001 534	.826	.0219	25.8	212	-.000012	.001 502	.826	.0215	25.8	216	-.000012	.001 474
550 000	.826	.0241	28.0	209	-.000013	.001 523	.826	.0236	28.0	213	-.000013	.001 491	.826	.0232	28.0	217	-.000012	.001 466
500 000	.826	.0262	30.7	211	-.000014	.001 510	.826	.0256	30.7	215	-.000014	.001 480	.826	.0252	30.7	219	-.000013	.001 455
450 000	.826	.0287	33.9	213	-.000016	.001 499	.826	.0282	33.9	217	-.000015	.001 469	.826	.0276	33.9	220	-.000014	.001 441
400 000	.826	.0319	38.0	215	-.000017	.001 482	.826	.0312	38.0	219	-.000016	.001 452	.826	.0307	38.0	223	-.000016	.001 428
350 000	.826	.0359	43.3	218	-.000019	.001 466	.826	.0352	43.3	222	-.000018	.001 439	.826	.0346	43.3	226	-.000018	.001 414
300 000	.826	.0413	50.4	220	-.000022	.001 450	.826	.0404	50.4	224	-.000021	.001 420	.826	.0398	50.4	228	-.000020	.001 398
250 000	.826	.0487	60.3	224	-.000025	.001 428	.826	.0478	60.3	228	-.000 024	.001 400	.826	.0470	60.3	231	-.000 024	.001 379
0 000	.824	.0566	71.1	229	-.000029	.001 409	.825	.0555	71.1	233	-.000 028	.001 381	.825	.0546	71.1	237	-.000 027	.001 360
000	.824	.0700	89.5	233	-.000035	.001 384	.825	.0687	89.5	237	-.000034	.001 357	.825	.0676	89.5	241	-.000033	.001 335
00	.824	.0867	113.	238	-.000043	.001 360	.824	.0851	113.	243	-.000041	.001 335	.824	.0837	113.	246	-.000040	.001 313

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.826	.0139	16.3	210	-.000008	.001 512	.826	.0137	16.3	213	-.000 007	.001 491	.826	.0135	16.3	216	-.000 007	.001 471
950 000	.826	.0145	17.0	211	-.000008	.001 507	.826	.0143	17.0	214	-.000 008	.001 485	.826	.0141	17.0	217	-.000 008	.001 466
900 000	.826	.0151	17.8	212	-.000008	.001 502	.826	0149	17.8	215	-.000 008	.001 480	.826	.0147	17.8	218	-.000 008	.001 458
850 000	.826	.0158	18.8	213	-.000009	.001 493	.826	.0156	18.8	216	-.000 008	.001 471	.826	.0154	18.8	219	-.000 008	.001 452
800 000	.826	.0166	19.8	214	-.000009	.001 485	.826	.0164	19.8	217	-.000 009	.001 463	.826	.0162	19.8	220	-.000 008	.001 444
750 000	.826	.0175	21.0	215	-.000009	.001 477	.826	.0173	21.0	218	-.000 009	.001 458	.826	.0171	21.0	221	-.000 009	.001 439
700 000	.826	.0186	22.4	216	-.000010	.001 469	.826	.0183	22.4	219	-.000 010	.001 450	.826	.0181	22.4	222	-.000 009	.001 431
650 000	.826	.0198	23.9	217	-.000010	.001 461	.826	.0195	23.9	220	-.000 010	.001 441	.826	.0192	23.9	223	-.000010	.001 422
600 000	.826	.0212	25.8	219	-.000011	.001 452	.826	.0209	25.8	222	-.000 011	.001 431	.826	.0206	25.8	225	-.000011	.001 414
550 000	.826	.0228	28.0	220	-.000012	.001 441	.826	.0225	28.0	223	-.000 012	.001 422	.826	.0222	28.0	226	-.000011	.001 403
500 000	.826	.0248	30.7	222	-.000013	.001 431	.826	.0245	30.7	225	-.000 013	.001 411	.826	.0241	30.7	228	-.000012	.001 392
450 000	.826	.0272	33.9	224	-.000014	.001 420	.826	.0268	33.9	227	-.000014	.001 400	.826	.0265	33.9	230	-.000013	.001 381
400 000	.826	.0302	38.0	226	-.000015	.001 406	.826	.0298	38.0	229	-.000 015	.001 387	.826	.0294	38.0	232	-.000015	.001 370
350 000	.826	.0341	43.3	229	-.000017	.001 392	.826	.0336	43.3	232	-.000 017	.001 373	.826	.0332	43.3	235	-.000016	.001 357
300 000	.826	.0392	50.4	231	-.000020	.001 376	.826	.0386	50.4	234	-.000019	.001 357	.826	.0382	50.4	237	-.000019	.001 340
250 000	.826	.0463	60.3	235	-.000023	.001 357	.826	.0457	60.3	238	-.000 022	.001 340	.826	.0451	60.3	240	-.000 022	.001 324
0 000	.825	.0538	71.1	240	-.000026	.001 338	.825	.0531	71.1	243	-.000 025	.001 321	.825	.0525	71.1	245	-.000 025	.001 305
000	.825	.0666	89.5	244	-.000032	.001 316	.825	.0658	89.5	247	-.000 031	.001 299	.825	.0649	89.5	250	-.000 030	.001 283
00	.824	.0825	113.	250	-.000039	.001 294	.825	.0815	113.	252	-.000 038	.001 278	.825	.0806	113.	255	-.000 037	.001 264

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{21} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} - \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XCIV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

290 MILES—466.71 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.831	.0164	15.6	166	-.000 011	.001 865	.831	.0158	15.6	173	-.000 010	.001 794	.831	.0153	15.6	179	-.000 010	.001 736
1 510 500	950 000	.831	.0171	16.4	167	-.000 012	.001 856	.831	.0165	16.4	174	-.000 011	.001 783	.831	.0159	16.4	179	-.000 010	.001 728
1 431 000	900 000	.831	.0179	17.3	168	-.000 012	.001 845	.831	.0173	17.3	175	-.000 011	.001 774	.831	.0167	17.3	180	-.000 010	.001 720
1 351 500	850 000	.831	.0188	18.2	169	-.000 013	.001 835	.831	.0181	18.2	175	-.000 012	.001 763	.831	.0176	18.2	181	-.000 011	.001 709
1 272 000	800 000	.831	.0199	19.3	170	-.000 013	.001 824	.831	.0191	19.3	176	-.000 012	.001 755	.831	.0185	19.3	182	-.000 011	.001 701
1 192 500	750 000	.831	.0210	20.6	171	-.000 014	.001 813	.831	.0202	20.6	177	-.000 013	.001 744	.831	.0196	20.6	183	-.000 012	.001 690
1 113 000	700 000	.831	.0224	22.0	172	-.000 015	.001 802	.831	.0215	22.0	179	-.000 014	.001 733	.831	.0209	22.0	184	-.000 013	.001 681
1 033 500	650 000	.831	.0239	23.7	173	-.000 015	.001 788	.831	.0230	23.7	180	-.000 014	.001 720	.831	.0223	23.7	185	-.000 013	.001 668
954 000	600 000	.831	.0256	25.6	174	-.000 016	.001 774	.831	.0247	25.6	181	-.000 015	.001 709	.831	.0239	25.6	186	-.000 014	.001 657
874 500	550 000	.831	.0278	28.0	176	-.000 018	.001 758	.831	.0267	28.0	182	-.000 016	.001 692	.831	.0259	28.0	188	-.000 015	.001 643
795 000	500 000	.831	.0301	30.6	177	-.000 019	.001 744	.831	.0289	30.6	184	-.000 018	.001 679	.831	.0281	30.6	190	-.000 017	.001 629
715 500	450 000	.831	.0332	34.2	179	-.000 021	.001 725	.831	.0321	34.2	186	-.000 019	.001 665	.831	.0311	34.2	191	-.000 018	.001 613
636 000	400 000	.831	.0368	38.3	181	-.000 023	.001 706	.831	.0355	38.3	188	-.000 021	.001 646	.831	.0345	38.3	193	-.000 020	.001 597
556 500	350 000	.831	.0414	43.2	182	-.000 025	.001 701	.831	.0398	43.2	189	-.000 024	.001 638	.831	.0387	43.2	194	-.000 022	.001 591
477 000	300 000	.831	.0476	50.4	185	-.000 029	.001 676	.831	.0459	50.4	192	-.000 027	.001 616	.831	.0446	50.4	197	-.000 025	.001 572
397 500	250 000	.831	.0561	60.4	189	-.000 034	.001 649	.831	.0542	60.4	195	-.000 031	.001 591	.831	.0527	60.4	201	-.000 030	.001 547
336 400	0000	.830	.0654	71.5	192	-.000 038	.001 624	.830	.0632	71.5	199	-.000 036	.001 569	.831	.0614	71.5	204	-.000 034	.001 526
266 800	000	.830	.0801	90.0	198	-.000 046	.001 580	.830	.0773	90.0	205	-.000 043	.001 526	.830	.0754	90.0	210	-.000 041	.001 487
0000	00	.811	.104	118.	225	-.000 058	.001 541	.812	.100	118.	231	-.000 054	.001 489	.812	.0975	118.	237	-.000 052	.001 451

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.831	.0149	15.6	183	-.000 009	.001 690	.831	.0145	15.6	187	-.000 009	.001 651	.831	.0143	15.6	191	-.000 008	.001 621
1 510 500	950 000	.831	.0155	16.4	184	-.000 009	.001 681	.831	.0152	16.4	188	-.000 009	.001 646	.831	.0149	16.4	192	-.000 009	.001 613
1 431 000	900 000	.831	.0163	17.3	185	-.000 010	.001 673	.831	.0159	17.3	189	-.000 009	.001 638	.831	.0156	17.3	193	-.000 009	.001 605
1 351 500	850 000	.831	.0171	18.2	186	-.000 010	.001 665	.831	.0167	18.2	190	-.000 010	.001 629	.831	.0164	18.2	193	-.000 009	.001 597
1 272 000	800 000	.831	.0181	19.3	187	-.000 011	.001 657	.831	.0177	19.3	191	-.000 010	.001 621	.831	.0173	19.3	195	-.000 010	.001 588
1 192 500	750 000	.831	.0191	20.6	188	-.000 011	.001 646	.831	.0187	20.6	192	-.000 011	.001 610	.831	.0183	20.6	195	-.000 010	.001 580
1 113 000	700 000	.831	.0203	22.0	189	-.000 012	.001 638	.831	.0199	22.0	193	-.000 012	.001 602	.831	.0195	22.0	197	-.000 011	.001 572
1 033 500	650 000	.831	.0217	23.7	190	-.000 013	.001 627	.831	.0213	23.7	194	-.000 012	.001 591	.831	.0209	23.7	198	-.000 012	.001 561
954 000	600 000	.831	.0233	25.6	191	-.000 014	.001 616	.831	.0228	25.6	195	-.000 013	.001 580	.831	.0224	25.6	199	-.000 013	.001 550
874 500	550 000	.831	.0253	28.0	193	-.000 015	.001 602	.831	.0248	28.0	197	-.000 014	.001 569	.831	.0243	28.0	200	-.000 014	.001 539
795 000	500 000	.831	.0274	30.6	194	-.000 016	.001 588	.831	.0268	30.6	198	-.000 015	.001 556	.831	.0263	30.6	202	-.000 015	.001 528
715 500	450 000	.831	.0303	34.2	196	-.000 017	.001 575	.831	.0297	34.2	200	-.000 017	.001 542	.831	.0292	34.2	204	-.000 016	.001 515
636 000	400 000	.831	.0336	38.3	198	-.000 019	.001 558	.831	.0330	38.3	202	-.000 018	.001 528	.831	.0324	38.3	206	-.000 018	.001 501
556 500	350 000	.831	.0378	43.2	199	-.000 021	.001 553	.831	.0370	43.2	203	-.000 020	.001 520	.832	.0363	43.2	207	-.000 020	.001 493
477 000	300 000	.831	.0436	50.4	202	-.000 024	.001 534	.831	.0426	50.4	206	-.000 023	.001 501	.831	.0419	50.4	210	-.000 022	.001 476
397 500	250 000	.831	.0514	60.4	205	-.000 028	.001 509	.831	.0503	60.4	210	-.000 027	.001 479	.831	.0495	60.4	213	-.000 026	.001 454
336 400	0000	.831	.0600	71.5	209	-.000 032	.001 490	.831	.0588	71.5	213	-.000 031	.001 460	.831	.0578	71.5	217	-.000 030	.001 435
266 800	000	.830	.0736	90.0	215	-.000 039	.001 452	.830	.0722	90.0	219	-.000 037	.001 424	.830	.0710	90.0	223	-.000 036	.001 400
0000	00	.813	.0953	118.	241	-.000 049	.001 418	.813	.0936	118.	246	-.000 048	.001 393	.814	.0919	118.	249	-.000 046	.001 368

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.831	.0140	15.6	195	-.000 008	.001 594	.831	.0138	15.6	198	-.000 008	.001 567	.831	.0136	15.6	200	-.000 008	.001 547
1 510 500	950 000	.831	.0146	16.4	195	-.000 008	.001 586	.831	.0144	16.4	198	-.000 008	.001 561	.831	.0142	16.4	201	-.000 008	.001 539
1 431 000	900 000	.831	.0153	17.3	196	-.000 009	.001 578	.831	.0151	17.3	199	-.000 008	.001 553	.831	.0149	17.3	202	-.000 008	.001 531
1 351 500	850 000	.831	.0161	18.2	197	-.000 009	.001 569	.831	.0159	18.2	200	-.000 009	.001 547	.831	.0157	18.2	202	-.000 009	.001 526
1 272 000	800 000	.831	.0170	19.3	198	-.000 010	.001 564	.831	.0168	19.3	201	-.000 009	.001 539	.831	.0165	19.3	204	-.000 009	.001 517
1 192 500	750 000	.831	.0180	20.6	199	-.000 010	.001 553	.831	.0178	20.6	202	-.000 010	.001 531	.831	.0175	20.6	205	-.000 010	.001 509
1 113 000	700 000	.831	.0192	22.0	200	-.000 011	.001 545	.831	.0189	22.0	203	-.000 010	.001 523	.831	.0186	22.0	206	-.000 010	.001 501
1 033 500	650 000	.831	.0205	23.7	201	-.000 011	.001 534	.831	.0202	23.7	204	-.000 011	.001 512	.831	.0199	23.7	207	-.000 011	.001 493
954 000	600 000	.832	.0220	25.6	202	-.000 012	.001 526	.832	.0217	25.6	206	-.000 012	.001 504	.832	.0214	25.6	208	-.000 011	.001 482
874 500	550 000	.832	.0239	28.0	204	-.000 013	.001 515	.832	.0236	28.0	207	-.000 013	.001 493	.832	.0232	28.0	209	-.000 012	.001 471
795 000	500 000	.832	.0259	30.6	205	-.000 014	.001 501	.832	.0255	30.6	208	-.000 014	.001 479	.832	.0252	30.6	211	-.000 013	.001 460
715 500	450 000	.832	.0287	34.2	207	-.000 015	.001 490	.832	.0283	34.2	210	-.000 015	.001 468	.832	.0279	34.2	213	-.000 015	.001 449
636 000	400 000	.832	.0319	38.3	209	-.000 017	.001 476	.832	.0314	38.3	212	-.000 017	.001 454	.832	.0310	38.3	215	-.000 016	.001 435
556 500	350 000	.832	.0358	43.2	210	-.000 019	.001 471	.832	.0353	43.2	213	-.000 019	.001 449	.832	.0348	43.2	216	-.000 018	.001 430
477 000	300 000	.831	.0412	50.4	213	-.000 022	.001 452	.831	.0407	50.4	216	-.000 021	.001 433	.831	.0401	50.4	219	-.000 021	.001 413
397 500	250 000	.831	.0488	60.4	217	-.000 025	.001 433	.831	.0480	60.4	220	-.000 025	.001 411	.831	.0475	60.4	222	-.000 024	.001 394
336 400	0000	.831	.0569	71.5	220	-.000 029	.001 413	.831	.0562	71.5	223	-.000 028	.001 394	.831	.0554	71.5	226	-.000 028	.001 375
266 800	000	.830	.0699	90.0	226	-.000 035	.001 378	.830	.0690	90.0	229	-.000 034	.001 362	.830	.0682	90.0	232	-.000 033	.001 345
0000	00	.814	.0906	118.	252	-.000 045	.001 349	.814	.0894	118.	255	-.000 043	.001 330	.814	.0885	118.	258	-.000 043	.001 316

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right)$ $\quad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$ $\quad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

TABLE XCV—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

COPPER CONDUCTORS—CONCENTRIC STRANDING AT 25°C—(77°F).

FOR ALUMINUM CONDUCTORS SEE OPPOSITE PAGE

300 MILES—482.80 Km.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.813	.0173	16.7	.188	-.000011	.001 812	.813	.0166	16.7	195	-.000011	.001 745	.813	.0161	16.7	200	-.000010	.001 694
950 000	.813	.0179	17.5	189	-.000012	.001 804	.813	.0173	17.5	195	-.000011	.001 736	.814	.0168	17.5	201	-.000010	.001 686
900 000	.813	.0187	18.3	190	-.000012	.001 795	.813	.0180	18.3	196	-.000011	.001 728	.814	.0175	18.3	202	-.000011	.001 677
850 000	.813	.0196	19.2	190	-.000013	.001 784	.813	.0188	19.2	197	-.000012	.001 719	.814	.0183	19.2	203	-.000011	.001 669
800 000	.813	.0205	20.3	192	-.000013	.001 776	.813	.0198	20.3	198	-.000012	.001 711	.814	.0192	20.3	204	-.000012	.001 660
750 000	.813	.0216	21.5	193	-.000014	.001 764	.813	.0208	21.5	199	-.000013	.001 700	.814	.0203	21.5	205	-.000012	.001 652
700 000	.813	.0229	22.9	194	-.000015	.001 753	.813	.0221	22.9	201	-.000014	.001 691	.814	.0214	22.9	206	-.000013	.001 641
650 000	.813	.0244	24.5	195	-.000016	.001 742	.813	.0235	24.5	202	-.000014	.001 680	.814	.0228	24.5	208	-.000014	.001 629
600 000	.813	.0261	26.5	197	-.000016	.001 728	.813	.0251	26.5	204	-.000015	.001 666	.814	.0244	26.5	209	-.000014	.001 618
550 000	.813	.0280	28.7	198	-.000018	.001 714	.813	.0271	28.7	205	-.000016	.001 655	.814	.0263	28.7	211	-.000015	.001 607
500 000	.813	.0305	31.5	200	-.000019	.001 700	.813	.0294	31.5	207	-.000018	.001 641	.814	.0286	31.5	212	-.000017	.001 596
450 000	.813	.0334	34.8	202	-.000021	.001 683	.813	.0322	34.8	209	-.000019	.001 626	.814	.0314	34.8	214	-.000018	.001 581
400 000	.813	.0370	39.0	205	-.000023	.001 666	.813	.0358	39.0	211	-.000021	.001 610	.813	.0348	39.0	217	-.000020	.001 565
350 000	.813	.0417	44.4	207	-.000025	.001 646	.813	.0402	44.4	214	-.000023	.001 590	.813	.0392	44.4	220	-.000022	.001 548
300 000	.813	.0478	51.7	210	-.000028	.001 624	.813	.0462	51.7	217	-.000027	.001 570	.813	.0450	51.7	222	-.000025	.001 528
250 000	.813	.0563	61.8	213	-.000033	.001 598	.813	.0546	61.8	220	-.000031	.001 548	.813	.0530	61.8	226	-.000029	.001 505
0000	.812	.0654	72.9	219	-.000038	.001 573	.812	.0633	72.9	225	-.000035	.001 522	.812	.0616	72.9	231	-.000033	.001 483
000	.811	.0809	91.8	223	-.000046	.001 545	.812	.0782	91.8	230	-.000043	.001 494	.812	.0763	91.8	236	-.000041	.001 458
00	.811	.100	116.	229	-.000055	.001 517	.811	.0968	116.	236	-.000052	.001 469	.811	.0944	116.	241	-.000049	.001 432

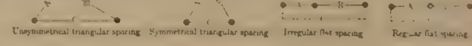
	15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.814	.0157	16.7	205	-.000009	.001 652	.814	.0154	16.7	209	-.000009	.001 615	.814	.0151	16.7	213	-.000009	.001 587
950 000	.814	.0163	17.5	206	-.000010	.001 643	.814	.0160	17.5	210	-.000009	.001 610	.814	.0157	17.5	214	-.000009	.001 579
900 000	.814	.0170	18.3	207	-.000010	.001 635	.814	.0167	18.3	211	-.000010	.001 601	.814	.0164	18.3	215	-.000009	.001 573
850 000	.814	.0179	19.2	208	-.000011	.001 629	.814	.0175	19.2	212	-.000010	.001 593	.814	.0172	19.2	216	-.000010	.001 565
800 000	.814	.0188	20.3	209	-.000011	.001 621	.814	.0184	20.3	213	-.000011	.001 587	.814	.0180	20.3	217	-.000010	.001 556
750 000	.814	.0197	21.5	210	-.000012	.001 610	.814	.0194	21.5	214	-.000011	.001 579	.814	.0190	21.5	218	-.000011	.001 548
700 000	.814	.0209	22.9	211	-.000012	.001 601	.814	.0205	22.9	215	-.000012	.001 567	.814	.0201	22.9	219	-.000011	.001 539
650 000	.814	.0223	24.5	213	-.000013	.001 593	.814	.0218	24.5	217	-.000012	.001 559	.814	.0214	24.5	220	-.000012	.001 531
600 000	.814	.0238	26.5	214	-.000014	.001 581	.814	.0233	26.5	218	-.000013	.001 548	.814	.0229	26.5	222	-.000013	.001 520
550 000	.814	.0257	28.7	216	-.000015	.001 570	.814	.0251	28.7	220	-.000014	.001 536	.814	.0247	28.7	224	-.000014	.001 511
500 000	.814	.0279	31.5	217	-.000016	.001 556	.814	.0273	31.5	222	-.000015	.001 525	.814	.0269	31.5	225	-.000015	.001 500
450 000	.814	.0306	34.8	219	-.000017	.001 545	.814	.0300	34.8	224	-.000017	.001 514	.814	.0295	34.8	227	-.000016	.001 486
400 000	.814	.0340	39.0	222	-.000019	.001 528	.814	.0333	39.0	226	-.000018	.001 497	.814	.0327	39.0	230	-.000018	.001 472
350 000	.814	.0382	44.4	224	-.000021	.001 511	.814	.0375	44.4	228	-.000020	.001 483	.814	.0369	44.4	232	-.000020	.001 458
300 000	.814	.0440	51.7	227	-.000024	.001 494	.814	.0431	51.7	231	-.000023	.001 463	.814	.0424	51.7	235	-.000022	.001 441
250 000	.814	.0519	61.8	231	-.000028	.001 472	.814	.0509	61.8	235	-.000027	.001 444	.814	.0501	61.8	239	-.000026	.001 421
0 000	.812	.0603	72.9	236	-.000032	.001 452	.813	.0592	72.9	240	-.000031	.001 424	.813	.0582	72.9	244	-.000030	.001 401
000	.812	.0747	91.8	241	-.000039	.001 427	.813	.0732	91.8	245	-.000037	.001 399	.813	.0720	91.8	249	-.000036	.001 376
00	.812	.0924	116.	246	-.000047	.001 401	.812	.0907	116.	250	-.000046	.001 376	.812	.0892	116.	254	-.000044	.001 354

	21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
	A		B		C		A		B		C		A		B		C	
	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 000 000	.814	.0148	16.7	216	-.000008	.001 559	.814	.0146	16.7	220	-.000008	.001 536	.814	.0144	16.7	222	-.000008	.001 517
950 000	.814	.0154	17.5	217	-.000009	.001 553	.814	.0152	17.5	220	-.000009	.001 531	.814	.0150	17.5	224	-.000008	.001 511
900 000	.814	.0161	18.3	218	-.000009	.001 548	.814	.0159	18.3	222	-.000009	.001 525	.814	.0157	18.3	224	-.000009	.001 503
850 000	.814	.0169	19.2	219	-.000009	.001 539	.814	.0166	19.2	222	-.000009	.001 517	.814	.0164	19.2	225	-.000009	.001 497
800 000	.814	.0177	20.3	220	-.000010	.001 531	.814	.0175	20.3	224	-.000010	.001 508	.814	.0172	20.3	226	-.000009	.001 489
750 000	.814	.0187	21.5	222	-.000010	.001 522	.814	.0184	21.5	225	-.000010	.001 503	.814	.0182	21.5	228	-.000010	.001 483
700 000	.814	.0198	22.9	223	-.000011	.001 514	.814	.0195	22.9	226	-.000011	.001 494	.814	.0193	22.9	229	-.000010	.001 475
650 000	.814	.0211	24.5	224	-.000012	.001 505	.814	.0208	24.5	227	-.000011	.001 486	.814	.0205	24.5	230	-.000011	.001 466
600 000	.814	.0226	26.5	226	-.000012	.001 497	.814	.0222	26.5	229	-.000012	.001 475	.814	.0220	26.5	231	-.000012	.001 458
550 000	.814	.0243	28.7	227	-.000013	.001 486	.814	.0240	28.7	230	-.000013	.001 466	.814	.0237	28.7	233	-.000013	.001 446
500 000	.814	.0264	31.5	229	-.000014	.001 475	.814	.0261	31.5	232	-.000014	.001 455	.814	.0257	31.5	235	-.000014	.001 435
450 000	.814	.0290	34.8	231	-.000016	.001 463	.814	.0286	34.8	234	-.000015	.001 444	.814	.0282	34.8	237	-.000015	.001 424
400 000	.814	.0322	39.0	233	-.000017	.001 449	.814	.0318	39.0	237	-.000017	.001 430	.814	.0314	39.0	239	-.000016	.001 413
350 000	.814	.0363	44.4	236	-.000019	.001 435	.814	.0358	44.4	239	-.000019	.001 415	.814	.0354	44.4	242	-.000018	.001 399
300 000	.814	.0418	51.7	239	-.000022	.001 418	.814	.0412	51.7	242	-.000021	.001 399	.814	.0407	51.7	245	-.000021	.001 382
250 000	.814	.0493	61.8	242	-.000025	.001 399	.814	.0487	61.8	245	-.000025	.001 382	.814	.0481	61.8	248	-.000024	.001 365
0 000	.813	.0573	72.9	247	-.000029	.001 379	.813	.0566	72.9	250	-.000028	.001 362	.813	.0559	72.9	253	-.000028	.001 345
000	.813	.0710	91.8	252	-.000035	.001 356	.813	.0701	91.8	255	-.000034	.001 339	.813	.0692	91.8	258	-.000033	.001 323
00	.813	.0879	116.	257	-.000043	.001 334	.813	.0868	116.	260	-.000042	.001 317	.813	.0859	116.	263	-.000041	.001 303

$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40,320} + \right)$ $B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right)$ $C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5,040} + \frac{Z^4Y^4}{362,880} + \right)$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $(o + jbl \times 10^{-6})$ in mhos per conductor, based upon values for r, x and b as given in Tables V, XI and XXI l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for hard drawn copper at 60 cycles.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.



Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

TABLE XCVI—AUXILIARY CONSTANTS FOR 60 CYCLE THREE-PHASE CIRCUITS

ALUMINUM CABLE STEEL REINFORCED AT 25°C—(77°F).

FOR COPPER CONDUCTORS SEE OPPOSITE PAGE

300 MILES—482.80 KM.

DISTANCE D BETWEEN CENTERS OF CONDUCTORS ★

CIRCULAR MILS OR A. W. G. (B & S)	COPPER EQUIVALENT CIRCULAR MILS OR A. W. G. BASED UPON COPPER 97% ALUMIN 61%	9 FEET—2.743 METERS						11 FEET—3.353 METERS						13 FEET—3.962 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.819	.017 5	16.0	171	-.000012	.001 921	.819	.016 8	16.0	178	-.000011	.001 848	.819	.016 3	16.0	184	-.000 011	.001 789
1 510 500	950 000	.819	.018 3	16.8	172	-.000013	.001 913	.819	.017 5	16.8	179	-.000012	.001 837	.819	.017 0	16.8	185	-.000011	.001 780
1 431 000	900 000	.819	.019 1	17.7	173	-.000013	.001 901	.819	.018 4	17.7	180	-.000012	.001 828	.819	.017 8	17.7	186	-.000011	.001 772
1 351 500	850 000	.820	.020 1	18.7	174	-.000014	.001 890	.820	.019 3	18.7	181	-.000013	.001 817	.820	.018 7	18.7	186	-.000012	.001 761
1 272 000	800 000	.820	.021 2	19.8	175	-.000014	.001 879	.820	.020 4	19.8	182	-.000 013	.001 809	.820	.019 7	19.8	187	-.000013	.001 752
1 192 500	750 000	.820	.022 4	21.1	176	-.000015	.001 868	.820	.021 6	21.1	183	-.000 014	.001 797	.820	.020 9	21.1	188	-.000013	.001 741
1 113 000	700 000	.820	.023 8	22.6	177	-.000016	.001 856	.820	.022 9	22.6	184	-.000 015	.001 786	.820	.022 2	22.6	190	-.000014	.001 732
1 033 500	650 000	.820	.025 4	24.3	178	-.000017	.001 842	.820	.024 5	24.3	185	-.000016	.001 772	.820	.023 7	24.3	191	-.000015	.001 718
954 000	600 000	.820	.027 3	26.3	180	-.000018	.001 828	.820	.026 3	26.3	187	-.000017	.001 761	.820	.025 5	26.3	192	-.000016	.001 707
874 500	550 000	.820	.029 6	28.7	181	-.000020	.001 811	.820	.028 5	28.7	188	-.000018	.001 744	.820	.027 6	28.7	194	-.000017	.001 693
795 000	500 000	.820	.032 0	31.4	183	-.000021	.001 797	.820	.030 8	31.4	189	-.000019	.001 730	.820	.029 9	31.4	195	-.000018	.001 679
715 500	450 000	.820	.035 4	35.1	185	-.000023	.001 778	.820	.034 2	35.1	192	-.000021	.001 716	.820	.033 1	35.1	197	-.000020	.001 662
636 000	400 000	.820	.039 2	39.3	187	-.000025	.001 758	.820	.037 8	39.3	194	-.000023	.001 696	.820	.036 7	39.3	199	-.000022	.001 645
556 500	350 000	.819	.044 1	44.3	188	-.000028	.001 752	.820	.042 4	44.3	195	-.000026	.001 687	.820	.041 3	44.3	200	-.000025	.001 639
477 000	300 000	.819	.050 7	51.7	191	-.000032	.001 727	.820	.048 9	51.7	198	-.000030	.001 665	.820	.047 6	51.7	203	-.000028	.001 620
397 500	250 000	.819	.059 8	62.0	194	-.000037	.001 699	.819	.057 7	62.0	201	-.000034	.001 639	.819	.056 1	62.0	207	-.000033	.001 594
336 400	0 000	.819	.069 7	73.3	198	-.000042	.001 673	.819	.067 3	73.3	205	-.000040	.001 617	.819	.065 4	73.3	210	-.000037	.001 577
266 800	000	.818	.085 4	92.3	204	-.000051	.001 628	.819	.082 4	92.3	211	-.000047	.001 572	.819	.080 3	92.3	217	-.000045	.001 532
0 000	00	.798	.110	121.	232	-.000064	.001 586	.799	.107	121.	239	-.000060	.001 533	.799	.104	121.	244	-.000057	.001 494

		15 FEET—4.572 METERS						17 FEET—5.182 METERS						19 FEET—5.791 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.819	.015 8	16.0	189	-.000010	.001 741	.819	.015 5	16.0	193	-.000 010	.001 701	.819	.015 2	16.0	197	-.000009	.001 670
1 510 500	950 000	.819	.016 5	16.8	190	-.000010	.001 732	.819	.016 2	16.8	194	-.000010	.001 696	.820	.015 9	16.8	198	-.000010	.001 662
1 431 000	900 000	.819	.017 3	17.7	191	-.000011	.001 724	.819	.017 0	17.7	195	-.000010	.001 687	.820	.016 6	17.7	198	-.000010	.001 654
1 351 500	850 000	.820	.018 2	18.7	191	-.000011	.001 716	.820	.017 8	18.7	196	-.000011	.001 679	.820	.017 5	18.7	199	-.000010	.001 645
1 272 000	800 000	.820	.019 2	19.8	192	-.000012	.001 707	.820	.018 8	19.8	197	-.000011	.001 670	.820	.018 4	19.8	200	-.000011	.001 637
1 192 500	750 000	.820	.020 3	21.1	193	-.000013	.001 696	.820	.019 9	21.1	198	-.000012	.001 659	.820	.019 5	21.1	201	-.000012	.001 628
1 113 000	700 000	.820	.021 7	22.6	195	-.000013	.001 687	.820	.021 2	22.6	199	-.000013	.001 651	.820	.020 8	22.6	203	-.000012	.001 620
1 033 500	650 000	.820	.023 2	24.3	196	-.000014	.001 676	.820	.022 6	24.3	200	-.000014	.001 639	.820	.022 2	24.3	204	-.000013	.001 609
954 000	600 000	.820	.024 9	26.3	197	-.000015	.001 665	.820	.024 3	26.3	201	-.000014	.001 628	.820	.023 9	26.3	205	-.000014	.001 597
874 500	550 000	.820	.027 0	28.7	198	-.000016	.001 651	.820	.026 4	28.7	203	-.000016	.001 617	.820	.025 9	28.7	207	-.000015	.001 586
795 000	500 000	.820	.029 2	31.4	200	-.000017	.001 637	.820	.028 6	31.4	204	-.000017	.001 603	.820	.028 1	31.4	208	-.000016	.001 575
715 500	450 000	.820	.032 3	35.1	202	-.000019	.001 623	.820	.031 7	35.1	206	-.000018	.001 589	.820	.031 1	35.1	210	-.000018	.001 561
636 000	400 000	.820	.035 8	39.3	204	-.000021	.001 606	.820	.035 1	39.3	208	-.000020	.001 575	.820	.034 5	39.3	212	-.000019	.001 547
556 500	350 000	.820	.040 3	44.3	205	-.000023	.001 600	.820	.039 4	44.3	209	-.000022	.001 566	.820	.038 7	44.3	213	-.000022	.001 538
477 000	300 000	.820	.046 4	51.7	208	-.000027	.001 580	.820	.045 4	51.7	212	-.000026	.001 547	.820	.044 6	51.7	216	-.000025	.001 521
397 500	250 000	.819	.054 7	62.0	212	-.000031	.001 555	.819	.05 36	62.0	216	-.000030	.001 524	.819	.052 7	62.0	220	-.000029	.001 499
336 400	0 000	.819	.063 9	73.3	215	-.000036	.001 535	.819	.062 7	73.3	220	-.000034	.001 504	.819	.061 6	73.3	223	-.000033	.001 479
266 800	000	.819	.078 4	92.3	222	-.000043	.001 496	.819	.077 0	92.3	226	-.000041	.001 468	.819	.075 6	92.3	230	-.000040	.001 442
0 000	00	.800	.102	121.	249	-.000055	.001 461	.800	.099 7	121.	253	-.000053	.001 434	.801	.097 9	121.	257	-.000051	.001 409

		21 FEET—6.401 METERS						23 FEET—7.010 METERS						25 FEET—7.620 METERS					
		A		B		C		A		B		C		A		B		C	
		a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2	a_1	ja_2	b_1	jb_2	c_1	jc_2
1 590 000	1 000 000	.819	.014 9	16.0	200	-.000 009	.001 642	.819	.014 7	16.0	204	-.000009	.001 614	.819	.014 5	16.0	206	-.000008	.001 594
1 510 500	950 000	.820	.015 6	16.8	201	-.000009	.001 634	.820	.015 3	16.8	204	-.000009	.001 609	.820	.015 1	16.8	207	-.000009	.001 586
1 431 000	900 000	.820	.016 3	17.7	202	-.000010	.001 625	.820	.016 1	17.7	205	-.000009	.001 600	.820	.015 9	17.7	208	-.000009	.001 578
1 351 500	850 000	.820	.017 2	18.7	203	-.000010	.001 617	.820	.016 9	18.7	206	-.000010	.001 594	.820	.016 7	18.7	209	-.000010	.001 572
1 272 000	800 000	.820	.018 2	19.8	204	-.000011	.001 611	.820	.017 9	19.8	207	-.000010	.001 586	.820	.017 6	19.8	210	-.000010	.001 563
1 192 500	750 000	.820	.019 2	21.1	205	-.000011	.001 600	.820	.018 9	21.1	208	-.000011	.001 578	.820	.018 7	21.1	211	-.000011	.001 555
1 113 000	700 000	.820	.020 4	22.6	206	-.000 012	.001 592	.820	.020 1	22.6	209	-.000012	.001 569	.820	.019 9	22.6	212	-.000011	.001 547
1 033 500	650 000	.820	.021 8	24.3	207	-.000013	.001 580	.820	.021 5	24.3	210	-.000012	.001 558	.820	.021 2	24.3	213	-.000012	.001 538
954 000	600 000	.820	.023 5	26.3	208	-.000013	.001 572	.820	.023 1	26.3	212	-.000013	.001 549	.820	.022 8	26.3	214	-.000013	.001 527
874 500	550 000	.820	.025 5	28.7	210	-.000014	.001 561	.820	.025 1	28.7	213	-.000014	.001 538	.820	.024 7	28.7	216	-.000014	.001 516
795 000	500 000	.820	.027 6	31.4	212	-.000016	.001 547	.820	.027 2	31.4	215	-.000015	.001 524	.820	.026 8	31.4	218	-.000015	.001 504
715 500	450 000	.820	.030 6	35.1	213	-.000017	.001 535	.820	.030 1	35.1	217	-.000017	.001 513	.820	.029 7	35.1	219	-.000016	.001 493
636 000	400 000	.820	.034 0	39.3	215	-.000 019	.001 521	.820	.033 4	39.3	219	-.000018	.001 499	.820	.033 0	39.3	222	-.000018	.001 479
556 500	350 000	.820	.038 1	44.3	216	-.000021	.001 516	.820	.037 6	44.3	220	-.000020	.001 493	.820	.037 1	44.3	223	-.000020	.001 473
477 000	300 000	.820	.043 9	51.7	220	-.000024	.001 496	.820	.043 3	51.7	223	-.000023	.001 476	.820	.042 7	51.7	225	-.000023	.001 456
397 500	250 000	.819	.051 9	62.0	223	-.000028	.001 476	.819	.051 2	62.0	226	-.000027	.001 454	.819	.050 6	62.0	229	-.000 026	.001 437
336 400	0 000	.819	.060 6	73.3	227	-.000032	.001 456	.819	.059 8	73.3	230	-.000031	.001 437	.819	.059 0	73.3	233	-.000030	.001 417
266 800	000	.819	.074 4	92.3	233	-.000 039	.001 420	.819	.073 5	92.3	236	-.000038	.001 403	.819	.072 7	92.3	239	-.000037	.001 386
0 000	00	.801	.096 5	121.	260	-.000049	.001 389	.802	.095 2	121.	263	-.000048	.001 370	.802	.094 2	121.	266	-.000047	.001 356

$$A = \cosh\theta = \left(1 + \frac{ZY}{2} + \frac{Z^2Y^2}{24} + \frac{Z^3Y^3}{720} + \frac{Z^4Y^4}{40{,}320} + \right) \qquad B = Z\frac{\sinh\theta}{\theta} = Z\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right) \qquad C = Y\frac{\sinh\theta}{\theta} = Y\left(1 + \frac{ZY}{6} + \frac{Z^2Y^2}{120} + \frac{Z^3Y^3}{5{,}040} + \frac{Z^4Y^4}{362{,}880} + \right)$$

in which Z is the total impedance $(rl + jxl)$ in ohms and Y is the total admittance $o + jbl \times 10^{-6}$ in mhos per conductor, based upon values for r, x and b as given in Tables VI, XII and XXII, l being the length of the circuit in miles. In the value of Y the leakage conductance gl is assumed as zero. Values of resistance r are for 60 cycles and a current density of 600 amperes per square inch. Values of reactance x for multiple layer conductors are for all current densities and for single layer conductors are for a current density of 600 amperes per square inch.

★ For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into D = A, B or C for symmetrical triangular spacing and into D = 1.26 A or B for regular flat spacing, it is immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing Symmetrical triangular spacing Irregular flat spacing Regular flat spacing

CHAPTER XXII

WILKINSON'S SIMPLIFIED FORMULAE FOR LONG LINE CONSTANTS

The tables of auxiliary constants in the preceding chapter are for 60-cycle circuits only. While 60 cycles is the standard frequency for power transmission in the United States and Canada, there are a number of important systems in these countries using 25 and 50 cycles. Abroad there is not the same degree of standardization in this respect and still other frequencies are in use. While it is not practicable to compile tables of auxiliary constants for each of these various frequencies a simple method of determining these constants for frequencies other than 60 cycles is desirable, and will be found in the formulae given in the six tables that follow.

The six tables actually comprise only three two-page tables, these being for frequencies of 25, 50 and 60 cycles respectively, the table for each frequency being double page in order to accommodate the range and small intervals of distance thought desirable. The inclusion of formulae for 60 cycles in these tables extends their usefulness and permits their application to the calculation of 60-cycle auxiliary constants for special conditions, as for instance, for all aluminum conductors, or for resistances at other temperatures than 25°C.; also, in the case of aluminum cable steel reinforced, for resistance and reactance at other current densities than 600 amp. per square inch, upon which density the constants in the preceding tables are based.

It will be noted that the simplified formulae give the values of each of the six component constants separately, in terms of numerical coefficients, which vary with the distance, and simple functions of the fundamental linear constants r, x and b. The formulae are tabulated for 25-cycle lines at intervals of 5 miles from 100 to 400 miles and at intervals of 10 miles between 400 and 500 miles. For frequencies of 50 and 60 cycles the range of distance is from 50 to 300 miles, the intervals of distance being 2 miles between 50 and 100 miles and 5 miles between 100 and 300 miles. For the 50- and 60-cycle frequencies additional formulae are given at the 5-mile intervals between 50 and 100 miles.

The formulae are in a form particularly convenient for slide rule calculation and the work and time required are the same, with the exception of the constant a_1, for lines of any length within the range covered by the tables. In the case of a_1 additional terms are added as the length of the line increases, the calculation thus being limited automatically to the number of terms actually required for the predetermined standard of accuracy.

The method of applying the formulae and the simplicity and directness of the calculations can best be shown by an example. Assume, for instance, that the constants are required for a three-phase, 25-cycle line 150 miles long, the conductors being No. 000 hard drawn copper at 25°C.; spaced 6 ft. apart. From Table

V........................	$r =$ .3488
IX	$x =$ .306
XIX.....................	$b =$ 2.45

Applying the coefficients of the formulae in Table XCVII for a distance of 150 miles, the constants are found as follows:

$$a_1 = 1 - .01125 \times .306 \times 2.45 - 21.09 \times 3488^2 \times 2.45^2 \times 10^{-6} = .992$$

$$a_2 = .01122 \times .3488 \times 2.45 = .00959$$
$$b_1 = 149.2 \times .3488 = 52.0$$
$$b_2 = 149.6 \times .306 + .5611 \times .3488^2 \times 2.45 = 45.9$$
$$c_1 = -.5616 \times .3488 \times 2.45^2 \times 10^{-6} = -.0000001$$
$$c_2 = 149.6 \times 2.45 \times 10^{-6} = .000366$$

Up to a distance of 500 miles the only change in the above calculation would be the substitution of different coefficients, corresponding to the distance, and, in the case of a_1, the calculation of one or, at most, two additional terms.

DERIVATION AND ACCURACY OF THE FORMULAE

The formulae are rationally derived from the convergent series expressions for the various constants, the simplification being accomplished by the omission of all negligible terms and by taking advantage of the fact that at any particular frequency, and within the limits of spacing and conductor sizes used in overhead transmission lines, the product of reactance, x, and susceptance b for non-magnetic conductors is nearly constant.

In the case of constant a_1 the formulae are exact to the number of terms used. The various terms are added to the expression for this constant at the smallest distance at which it is possible, within the range of the tables, for the added term to reach a value of 0.0005. Since the smallest tabulated value of a_1 is 0.811, the maximum error in the case of this constant is less than 1 in 1,600. As the actual values of x and b are used in this case, the formulae for a_1, are equally accurate for copper or A. C. S. R. conductors.

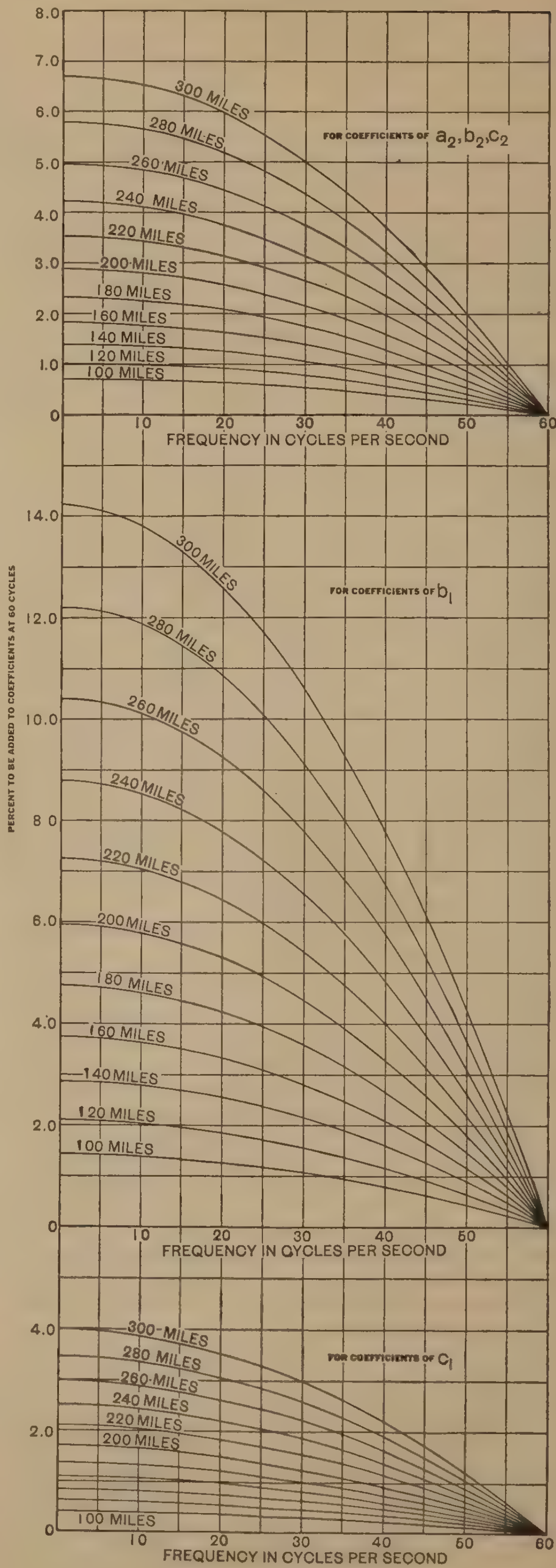
In the case of the remaining five constants the numerical coefficients tabulated represent the values of terms which are functions only of the distance l and the product xb. By assuming for each frequency an intermediate constant value of xb the algebraic coefficients in the various expressions are reduced to a fixed numerical value. In regard to the intermediate value assumed for xb it is to be noted that the variation in values of xb is greater for aluminum cable steel rein-

forced than for copper or all aluminum conductors, this being due to the higher reactance of single layer A. C. S. R. conductors caused by the steel core. If the coefficients are calculated using an intermediate value of xb based on the range of values for both copper and A. C. S. R. conductors the formulae will be equally accurate for either type of conductor. This accuracy will be less, however, for copper and all aluminum conductors, than it might be made by basing the value of xb on the narrower range of values for copper conductors only. Since the fundamental constants for copper conductors are quite definite and known to a high degree of accuracy, while those for A. C. S. R. conductors are less accurately determined and standardized and are not constant but vary with the current density in the conductor, it seemed, on the whole, desirable to calculate the coefficients primarily with reference to obtaining the maximum accuracy for copper and all aluminum conductors.

In the simplified formulae as presented in Tables XCVII to CII, the maximum error in the determination of any of the remaining five constants for copper or all aluminum conductors, including both the effect of the omitted terms and the variations in xb values, is 1 in 700 or one-seventh of 1 per cent. The corresponding maximum error in the case of aluminum cable steel reinforced, based on a current density of 600 amp. per square inch is 1.1 per cent. On the basis of a current density of 1,200 amp. per square inch, the possible maximum error for A. C. S. R. conductors would be increased to 2.1 per cent. It should be noted that the percentage errors mentioned can occur only under the most unfavorable combination of conditions possible within the range of the tables. That is, they are the possible errors for 60-cycle lines 300 miles long and 25-cycle lines 500 miles long, with the most unfavorable combination of size and spacing of conductor. The error rapidly decreases with shorter lines and lower frequencies and in many cases the actual value of xb will be nearer or equal to the fixed value on which the formulae are based. Under normal conditions, therefore, the errors will be much less than the maximums stated above and in view of the numerous elements of uncertainty as to the exact value of the fundamental constants of the circuit, as outlined in the previous chapter, these simplified formulae can be used for any practical case with an accuracy fully equal to that of the basic assumptions.

INTERPOLATION FOR DISTANCE AND FREQUENCY

The coefficients of the simplified formulae change, for the different constants, approximately in proportion to various powers of the distance l and for the most precise results interpolation for distance would be made in accordance with the ratios of these powers of l. It is found, however, that due to the small tabular intervals of distance and the fact that the terms most influenced by the method of interpolation represent only a small percentage of the value of the corresponding constant, the tabular differences can be interpolated by



simple proportion with a maximum error in the value of any constant, except c_1, of 1 in 2,600. The possible error in the case of c_1, is 1 in 900, but as this constant is so small and unimportant, and is only tabulated to two significant figures, this exception may be disregarded. Since the linear and 60-cycle auxiliary constants are, with the exception of the resistance of copper conductors, tabulated only to three figures, it will be seen that interpolation can be made by proportional differences with absolutely no effect on the accuracy of results.

While the simplified formulae cover the only transmission frequencies in practical use in this country occasion will sometimes arise where the constants are required for other frequencies. The coefficients for any frequency up to 60 cycles can be determined very readily by means of the curves on the previous page. It will be noted that with the exception of the constant a_1 the coefficients for any particular distance increase with lower frequencies. That is, the coefficients at any frequency less than 60 cycles will be greater than those at 60 cycles by a percentage which can be determined and which will vary with the distance and for each constant. In the case of a_1 the actual values of the various terms at the particular frequency under consideration are used and no interpolation is required. In the case of the remaining constants it is found that the percentage variation with frequency of the coefficients of constants a_2, b_2 and c_2 is nearly the same, and for practical purposes can be assigned an average value which will give a result accurate within 0.1 per cent. The percentage to be added to the coefficients at 60 cycles in order to obtain those for any other frequency are shown graphically on the adjoining curves. The percentage is found by starting at the assumed frequency on the bottom scale of that section of the diagram corresponding to the constant whose coefficient is required, moving vertically to an intersection with the curve representing the distance, thence horizontally to the left to the per cent required. As an example, assume that the coefficients for the simplified formulae are required for a 40-cycle line 160 miles long. From the curves the following percentages will be found:

a_2, b_2, c_2	1.0
b_1	2.1
c_1	0.6

The coefficients for a 40-cycle line 160 miles long will then be found by adding the above percentages to the coefficients of a 60-cycle line 160 miles long.

TABLE XCVII—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 25 CYCLE LINES

DISTANCE		a_1	ja_2	b_1	jb_2	c_1	jc_2
MILES	KM.						
100	160.9	$1-.005000\,xb$	$.004994\,rb$	$99.7\,r$	$99.88x + .1665\,r^2b$	$-.1666\,rb^2 \times 10^{-6}$	$99.88\,b \times 10^{-6}$
105	169.0	1-.005512 "	.005505 "	104.7 "	104.9 " + .1927 "	− .1928 " "	104.9 " "
110	177.0	1-.006050 "	.006041 "	109.7 "	109.8 " + .2215 "	− .2216 " "	109.8 " "
115	185.1	1-.006612 "	.006602 "	114.6 "	114.8 " + .2531 "	− .2532 " "	114.8 " "
120	193.1	1-.007200 "	.007187 "	119.6 "	119.8 " + .2875 "	− .2877 " "	119.8 " "
125	201.2	1-.007812 "	.007797 "	124.5 "	124.8 " + .3250 "	− .3252 " "	124.8 " "
130	209.2	1-.008450 "	.008433 "	129.5 "	129.7 " + .3655 "	− .3657 " "	129.7 " "
135	217.3	1-.009112 "	.009092 "	134.4 "	134.7 " + .4092 "	− .4095 " "	134.7 " "
140	225.3	1-.009800 "	.009777 "	139.3 "	139.7 " + .4563 "	− .4567 " "	139.7 " "
145	233.4	$1-.01051\,xb - 18.42\,r^2b^2 \times 10^{-6}$	.01049 "	144.2 "	144.6 " + .5069 "	− .5073 " "	144.6 " "
150	241.4	1-.01125 " − 21.09 "	.01122 "	149.2 "	149.6 " + .5611 "	− .5616 " "	149.6 " "
155	249.4	1-.01201 " − 24.05 "	.01198 "	154.1 "	154.5 " + .6190 "	− .6195 " "	154.5 " "
160	257.5	$1-.01280$ " $+ 27.31(x^2b^2 - r^2b^2) \times 10^{-6}$	.01276 "	159.0 "	159.5 " + .6807 "	− .6814 " "	159.5 " "
165	265.5	1-.01361 " + 30.88 " "	.01357 "	163.9 "	164.5 " + .7464 "	− .7472 " "	164.5 " "
170	273.6	1-.01445 " + 34.80 " "	.01440 "	168.8 "	169.4 " + .8162 "	− .8171 " "	169.4 " "
175	281.6	1-.01531 " + 39.08 " "	.01525 "	173.7 "	174.3 " + .8902 "	− .8912 " "	174.3 " "
180	289.7	1-.01620 " + 43.74 " "	.01613 "	178.6 "	179.3 " + .9685 "	− .9697 " "	179.3 " "
185	297.7	1-.01711 " + 48.81 " "	.01704 "	183.4 "	184.2 " +1.051 "	−1.053 " "	184.2 " "
190	305.8	1-.01805 " + 54.30 " "	.01797 "	188.3 "	189.2 " +1.139 "	−1.140 " "	189.2 " "
195	313.8	1-.01901 " + 60.25 " "	.01892 "	193.2 "	194.1 " +1.231 "	−1.232 " "	194.1 " "
200	321.9	1-.02000 " + 66.67 " "	.01990 "	198.0 "	199.0 " +1.327 "	−1.329 " "	199.0 " "
205	329.9	1-.02101 " + 73.59 " "	.02090 "	202.9 "	203.9 " +1.429 "	−1.431 " "	203.9 " "
210	338.0	1-.02205 " + 81.03 " "	.02193 "	207.7 "	208.9 " +1.536 "	−1.539 " "	208.8 " "
215	346.0	1-.02311 " + 89.03 " "	.02298 "	212.5 "	213.8 " +1.648 "	−1.651 " "	213.8 " "
220	354.1	1-.02420 " + 97.61 " "	.02406 "	217.4 "	218.7 " +1.765 "	−1.768 " "	218.7 " "
225	362.1	1-.02531 " +106.8 " "	.02515 "	222.2 "	223.6 " +1.888 "	−1.891 " "	223.6 " "
230	370.2	1-.02645 " +116.6 " "	.02628 "	227.0 "	228.5 " +2.016 "	−2.020 " "	228.5 " "
235	378.2	1-.02761 " +127.1 " "	.02742 "	231.8 "	233.4 " +2.150 "	−2.154 " "	233.4 " "
240	386.2	1-.02880 " +138.2 " "	.02859 "	236.6 "	238.3 " +2.289 "	−2.294 " "	238.3 " "
245	394.3	1-.03001 " +150.1 " "	.02979 "	241.4 "	243.2 " +2.435 "	−2.440 " "	243.2 " "
250	402.3	1-.03125 " +162.8 " "	.03101 "	246.1 "	248.1 " +2.586 "	−2.592 " "	248.1 " "
255	410.4	1-.03251 " +176.2 " "	.03225 "	250.9 "	253.0 " +2.744 "	−2.750 " "	253.0 " "
260	418.4	1-.03380 " +190.4 " "	.03352 "	255.7 "	257.8 " +2.907 "	−2.915 " "	257.8 " "
265	426.5	1-.03511 " +205.5 " "	.03481 "	260.4 "	262.7 " +3.077 "	−3.086 " "	262.7 " "
270	434.5	1-.03645 " +221.4 " "	.03612 "	265.1 "	267.6 " +3.254 "	−3.263 " "	267.6 " "
275	442.6	1-.03781 " +238.3 " "	.03746 "	269.9 "	272.4 " +3.437 "	−3.447 " "	272.4 " "

TABLE XCVIII—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 25 CYCLE LINES

DISTANCE Miles	DISTANCE Km.	a_1	ja_2	b_1	jb_2	c_1	jc_2
280	450.6	$1-.03920\,xb+256.1\,(x^2b^2-r^2b^2)\times10^{-6}$	.03882 rb	274.6 r	277.3 x + 3.627 r^2b	− 3.637 $rb^2\times10^{-6}$	277.3 $b\times10^{-6}$
285	458.7	1−.04061 " + 274.9 " "	.04020 "	279.3 "	282.1 " + 3.823 "	− 3.835 " "	282.1 " "
290	466.7	1−.04205 " + 294.7 " "	.04161 "	284.0 "	287.0 " + 4.027 "	− 4.040 " "	287.0 " "
295	474.8	1−.04351 " + 315.6 " "	.04304 "	288.7 "	291.8 " + 4.237 "	− 4.251 " "	291.8 " "
300	482.8	1−.04500 " + 337.5 " "	.04450 "	293.4 "	296.7 " + 4.455 "	− 4.470 " "	296.7 " "
305	490.8	1−.04651 " + 360.6 " "	.04598 "	298.0 "	301.5 " + 4.680 "	− 4.696 " "	301.5 " "
310	498.9	1−.04805 " + 384.8 " "	.04748 "	302.6 "	306.3 " + 4.912 "	− 4.930 " "	306.3 " "
315	506.9	1−.04961 " + 410.2 " "	.04901 "	307.3 "	311.1 " + 5.152 "	− 5.171 " "	311.1 " "
320	515.0	1−.05120 " + 436.9 " "	.05055 "	311.9 "	316.0 " + 5.399 "	− 5.420 " "	316.0 " "
325	523.0	1−.05282 " + 464.9 " "	.05213 "	316.6 "	320.8 " + 5.655 "	− 5.677 " "	320.8 " "
330	531.1	1−.05445 " + 494.1 " "	.05371 "	321.2 "	325.6 " + 5.917 "	− 5.941 " "	325.6 " "
335	539.1	1−.05612 " + 524.8 " "	.05533 "	325.8 "	330.4 " + 6.188 "	− 6.214 " "	330.4 " "
340	547.2	1−.05780 " + 556.8 " "	.05697 "	330.3 "	335.2 " + 6.466 "	− 6.494 " "	335.2 " "
345	555.2	1−.05952 " + 590.3 " "	.05864 "	334.9 "	340.0 " + 6.753 "	− 6.784 " "	340.0 " "
350	563.3	1−.06125 " + 625.3 " "	.06032 "	339.4 "	344.7 " + 7.048 "	− 7.081 " "	344.7 " "
355	571.3	1−.06302 " + 661.8 " "	.06203 "	344.0 "	349.5 " + 7.352 "	− 7.387 " "	349.5 " "
360	579.4	1−.06480 " + 699.8 " "	.06376 "	348.5 "	354.3 " + 7.664 "	− 7.701 " "	354.3 " "
365	587.4	1−.06662 " + 739.6 " "	.06552 "	353.1 "	359.0 " + 7.985 "	− 8.025 " "	359.0 " "
370	595.5	1−.06845 " + 780.9 " "	.06729 "	357.6 "	363.8 " + 8.314 "	− 8.357 " "	363.8 " "
375	603.5	1−.07032 " + 824.1 " "	.06909 "	362.1 "	368.5 " + 8.652 "	− 8.698 " "	368.5 " "
380	611.6	1−.07220 " + 868.8 " "	.07091 "	366.5 "	373.2 " + 8.998 "	− 9.047 " "	373.2 " "
385	619.6	1−.07412 xb + 915.5 " "	.07275 "	371.0 "	378.0 " + 9.354 "	− 9.407 " "	378.0 " "
390	627.6	1−.07605 " + 963.9 " "	.07462 "	375.4 "	382.7 " + 9.719 "	− 9.775 " "	382.7 " "
395	635.7	1−.07802 " + 1014 " "	.07651 "	379.9 "	387.4 " + 10.09 "	−10.15 " "	387.4 " "
400	643.7	1−.08000 " + 1067 " "	.07842 "	384.3 "	392.1 " + 10.48 "	−10.54 " "	392.1 " "
410	659.8	1−.08405 " + 1177 " "	.08231 "	393.1 "	401.5 " + 11.27 "	−11.34 " "	401.5 " "
420	675.9	1−.08820 " + 1297 " "	.08627 "	401.8 "	410.9 " + 12.11 "	−12.19 " "	410.9 " "
430	692.0	$1-.09245\,xb+[1424(x^2b^2-r^2b^2)+26.34\,r^2xb^3]\times10^{-6}$	.09033 "	410.5 "	420.2 " + 12.98 "	−13.07 " "	420.2 " "
440	708.1	1−.09680 " + [1562 " + 30.24 "] "	.09448 "	419.1 "	429.5 " + 13.89 "	−13.99 " "	429.5 " "
450	724.2	1−.1013 " + [1709 " + 34.60 "] "	.09871 "	427.7 "	438.8 " + 14.85 "	−14.96 " "	438.8 " "
460	740.3	1−.1058 " + [1866 " + 39.48 "] "	.1030 "	436.2 "	448.1 " + 15.84 "	−15.97 " "	448.1 " "
470	756.4	1−.1105 " + [2033 " + 44.91 "] "	.1074 "	444.6 "	457.3 " + 16.88 "	−17.02 " "	457.3 " "
480	772.5	1−.1152 " + [2212 " + 50.96 "] "	.1119 "	453.0 "	466.4 " + 17.96 "	−18.12 " "	466.4 " "
490	788.6	1−.1201 " + [2402 " + 57.67 "] "	.1165 "	461.3 "	475.6 " + 19.08 "	−19.26 " "	475.6 " "
500	804.7	1−.1250 " + [2604 " + 65.10 "] "	.1211 "	469.5 "	484.7 " + 20.25 "	−20.45 " "	484.7 " "

TABLE XCIX—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 50 CYCLE LINES

DISTANCE		a_1	ja_2	b_1	jb_2	c_1	jc_2
MILES	KM.						
50	80.47	1 − .001250 xb	.001249 rb	49.88 r	49.94 x + .02081 r^2b	− .02082 $rb^2 \times 10^{-6}$	49.94 $b \times 10^{-6}$
52	83.69	1 − .001352 "	.001350 "	51.86 "	51.93 " + .02341 "	− .02342 " × "	51.93 " "
54	86.90	1 − .001458 "	.001456 "	53.84 "	53.92 " + .02621 "	− .02622 " × "	53.92 " "
55	88.51	1 − .001513 "	.001510 "	54.83 "	54.92 " + .02769 "	− .02771 " × "	54.92 " "
56	90.12	1 − .001568 "	.001566 "	55.82 "	55.91 " + .02923 "	− .02924 " × "	55.91 " "
58	93.34	1 − .001682 "	.001679 "	57.81 "	57.90 " + .03247 "	− .03249 " × "	57.90 " "
60	96.56	1 − .001800 "	.001797 "	59.79 "	59.89 " + .03594 "	− .03596 " × "	59.89 " "
62	99.78	1 − .001922 "	.001918 "	61.76 "	61.88 " + .03965 "	− .03968 " × "	61.88 " "
64	103.0	1 − .002048 "	.002044 "	63.74 "	63.87 " + .04361 "	− .04364 " × "	63.87 " "
65	104.6	1 − .002113 "	.002108 "	64.73 "	64.86 " + .04569 "	− .04572 " × "	64.86 " "
66	106.2	1 − .002178 "	.002173 "	65.71 "	65.86 " + .04782 "	− .04785 " × "	65.86 " "
68	109.4	1 − .002312 "	.002307 "	67.69 "	67.84 " + .05230 "	− .05233 " × "	67.84 " "
70	112.7	1 − .002450 "	.002444 "	69.66 "	69.83 " + .05704 "	− .05708 " × "	69.83 " "
72	115.9	1 − .002592 "	.002585 "	71.63 "	71.81 " + .06206 "	− .06211 " × "	71.81 " "
74	119.1	1 − .002738 "	.002731 "	73.60 "	73.80 " + .06737 "	− .06743 " × "	73.80 " "
75	120.7	1 − .002813 "	.002805 "	74.58 "	74.79 " + .07014 "	− .07020 " × "	74.79 " "
76	122.3	1 − .002888 "	.002880 "	75.56 "	75.78 " + .07297 "	− .07304 " × "	75.78 " "
78	125.5	1 − .003042 "	.003033 "	77.53 "	77.77 " + .07888 "	− .07895 " × "	77.77 " "
80	128.8	1 − .003200 "	.003190 "	79.49 "	79.75 " + .08509 "	− .08517 " × "	79.75 " "
82	132.0	1 − .003362 "	.003351 "	81.46 "	81.73 " + .09162 "	− .09171 " × "	81.73 " "
84	135.2	1 − .003528 "	.003516 "	83.42 "	83.71 " + .09848 "	− .09858 " × "	83.71 " "
85	136.8	1 − .003613 "	.003600 "	84.39 "	84.70 " + .1020 "	− .1021 " × "	84.70 " "
86	138.4	1 − .003698 "	.003685 "	85.37 "	85.68 " + .1057 "	− .1058 " × "	85.68 " "
88	141.6	1 − .003872 "	.003857 "	87.32 "	87.66 " + .1132 "	− .1133 " × "	87.66 " "
90	144.8	1 − .004050 "	.004034 "	89.28 "	89.64 " + .1211 "	− .1212 " × "	89.64 " "
92	148.1	1 − .004232 "	.004214 "	91.23 "	91.61 " + .1293 "	− .1295 " × "	91.61 " "
94	151.3	1 − .004418 "	.004399 "	93.18 "	93.59 " + .1379 "	− .1381 " × "	93.59 " "
95	152.9	1 − .004513 "	.004492 "	94.15 "	94.57 " + .1423 "	− .1425 " × "	94.57 " "
96	154.5	1 − .004608 "	.004587 "	95.12 "	95.56 " + .1469 "	− .1471 " × "	95.56 " "
98	157.7	1 − .004802 "	.004779 "	97.07 "	97.53 " + .1562 "	− .1564 " × "	97.53 " "
100	160.9	1 − .005000 "	.004975 "	99.01 "	99.51 " + .1659 "	− .1662 " × "	99.51 " "
105	169.0	1 − .005512 xb − 5.065 $r^2b^2 \times 10^{-6}$	.005483 "	103.9 "	104.4 " + .1920 "	− .1923 " × "	104.4 " "
110	177.0	1 − .006050 " − 6.101 " "	.006014 "	108.7 "	109.3 " + .2206 "	− .2210 " × "	109.3 " "
115	185.1	1 − .006612 " − 7.288 " "	.006569 "	113.5 "	114.2 " + .2520 "	− .2525 " × "	114.2 " "
120	193.1	1 − .007200 " − 8.640 " "	.007149 "	118.3 "	119.1 " + .2862 "	− .2868 " × "	119.1 " "
125	201.2	1 − .007812 " − 10.17 " "	.007752 "	123.1 "	124.0 " + .3233 "	− .3240 " × "	124.0 " "

TABLE C—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 50 CYCLE LINES

DISTANCE		a_1	ja_2	b_1	jb_2	c_1	jc_2
MILES	KM.						
130	209.2	$1-.008450xb-11.90r^2b^2\times10^{-6}$	$.008379rb$	$127.8r$	$128.9x+.3634r^2b$	$-.3643rb^2\times10^{-6}$	$128.9b\times10^{-6}$
135	217.3	1−.009112 " −13.84 " "	.009030 "	132.6 "	133.8 " +.4067 "	−.4078 " "	133.8 " "
140	225.3	1−.009800 " −16.01 " "	.009705 "	137.3 "	138.6 " +.4533 "	−.4547 " "	138.6 " "
145	233.4	1−.01051 " −18.42 " "	.01040 "	142.0 "	143.5 " +.5033 "	−.5049 " "	143.5 " "
150	241.4	1−.01125 " −21.09 " "	.01113 "	146.7 "	148.3 " +.5569 "	−.5588 " "	148.3 " "
155	249.4	1−.01201 " −24.05 " "	.01187 "	151.3 "	153.2 " +.6140 "	−.6162 " "	153.2 " "
160	257.5	1−.01280 " −27.31 " "	.01264 "	156.0 "	158.0 " +.6749 "	−.6775 " "	158.0 " "
165	265.5	1−.01361 " −30.88 " "	.01343 "	160.6 "	162.8 " +.7396 "	−.7426 " "	162.8 " "
170	273.6	1−.01445 " −34.80 " "	.01424 "	165.2 "	167.6 " +.8083 "	−.8118 " "	167.6 " "
175	281.6	1−.01531 " −39.08 " "	.01508 "	169.7 "	172.3 " +.8810 "	−.8851 " "	172.3 " "
180	289.7	1−.01620 " −43.74 " "	.01594 "	174.3 "	177.1 " +.9580 "	−.9627 " "	177.1 " "
185	297.7	1−.01711 " −48.81 " "	.01682 "	178.8 "	181.9 " +1.039 "	−1.045 " "	181.9 " "
190	305.8	$1-.01805xb+54.30(x^2b^2-r^2b^2)\times10^{-6}$	.01773 "	183.3 "	186.6 " +1.125 "	−1.131 " "	186.6 " "
195	313.8	1−.01901 " +60.25 " "	.01865 "	187.7 "	191.3 " +1.215 "	−1.222 " "	191.3 " "
200	321.9	1−.02000 " +66.67 " "	.01960 "	192.1 "	196.1 " +1.310 "	−1.318 " "	196.1 " "
205	329.9	1−.02101 " +73.59 " "	.02058 "	196.6 "	200.8 " +1.409 "	−1.418 " "	200.8 " "
210	338.0	1−.02205 " +81.03 " "	.02157 "	200.9 "	205.4 " +1.513 "	−1.523 " "	205.4 " "
215	346.0	1−.02311 " +89.03 " "	.02258 "	205.3 "	210.1 " +1.622 "	−1.634 " "	210.1 " "
220	354.1	1−.02420 " +97.61 " "	.02362 "	209.6 "	214.8 " +1.736 "	−1.749 " "	214.8 " "
225	362.1	1−.02531 " +106.8 " "	.02468 "	213.8 "	219.4 " +1.856 "	−1.870 " "	219.4 " "
230	370.1	1−.02645 " +116.6 " "	.02576 "	218.1 "	224.0 " +1.980 "	−1.996 " "	224.0 " "
235	378.2	1−.02761 " +127.1 " "	.02686 "	222.3 "	228.6 " +2.110 "	−2.128 " "	228.6 " "
240	386.2	1−.02880 " +138.2 " "	.02798 "	226.5 "	233.2 " +2.245 "	−2.265 " "	233.2 " "
245	394.3	1−.03001 " +150.1 " "	.02912 "	230.6 "	237.8 " +2.385 "	−2.407 " "	237.8 " "
250	402.3	1−.03125 " +162.8 " "	.03028 "	234.7 "	242.3 " +2.532 "	−2.556 " "	242.3 " "
255	410.4	1−.03251 " +176.2 " "	.03147 "	238.8 "	246.9 " +2.683 "	−2.710 " "	246.9 " "
260	418.4	1−.03380 " +190.4 " "	.03267 "	242.8 "	251.4 " +2.841 "	−2.870 " "	251.4 " "
265	426.5	1−.03511 " +205.5 " "	.03389 "	246.9 "	255.9 " +3.005 "	−3.037 " "	255.9 " "
270	434.5	$1-.03645xb+[221.4(x^2b^2-r^2b^2)+1.614r^2xb^3]\times10^{-6}$	.03514 "	250.8 "	260.4 " +3.174 "	−3.209 " "	260.4 " "
275	442.6	1−.03781 " +[238.3 " +1.802 "] "	.03640 "	254.7 "	264.8 " +3.349 "	−3.388 " "	264.8 " "
280	450.6	1−.03920 " +[256.1 " +2.008 "] "	.03768 "	258.6 "	269.2 " +3.531 "	−3.573 " "	269.2 " "
285	458.7	1−.04061 " +[274.9 " +2.749 "] "	.03898 "	262.5 "	273.7 " +3.719 "	−3.765 " "	273.7 " "
290	466.7	1−.04205 " +[294.7 " +2.478 "] "	.04030 "	266.3 "	278.1 " +3.913 "	−3.963 " "	278.1 " "
295	474.8	1−.04351 " +[315.6 " +2.746 "] "	.04164 "	270.1 "	282.4 " +4.113 "	−4.168 " "	282.4 " "
300	482.8	1−.04500 " +[337.5 " +3.038 "] "	.04300 "	273.8 "	286.8 " +4.320 "	−4.380 " "	286.8 " "

TABLE CI—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 60 CYCLE LINES

DISTANCE		a_1	ja_2	b_1	jb_2	c_1	jc_2
MILES	KM.						
50	80.47	1−.001250 xb	.001248 rb	49.81 r	49.91 x + .02080 r^2b	−.02081 $rb^2 \times 10^{-6}$	49.91 $b \times 10^{-6}$
52	83.69	1−.001352 ″	.001349 ″	51.80 ″	51.90 ″ + .02339 ″	−.02341 ″ ″	51.90 ″ ″
54	86.90	1−.001458 ″	.001455 ″	53.77 ″	53.89 ″ + .02620 ″	−.02621 ″ ″	53.89 ″ ″
55	88.51	1−.001513 ″	.001510 ″	54.76 ″	54.91 ″ + .02768 ″	−.02770 ″ ″	54.91 ″ ″
56	90.12	1−.001568 ″	.001565 ″	55.75 ″	55.87 ″ + .02921 ″	−.02923 ″ ″	55.87 ″ ″
58	93.34	1−.001682 ″	.001678 ″	57.72 ″	57.86 ″ + .03245 ″	−.03247 ″ ″	57.86 ″ ″
60	96.56	1−.001800 ″	.001796 ″	59.69 ″	59.84 ″ + .03592 ″	−.03595 ″ ″	59.84 ″ ″
62	99.78	1−.001922 ″	.001917 ″	61.66 ″	61.83 ″ + .03962 ″	−.03966 ″ ″	61.83 ″ ″
64	103.0	1−.002048 ″	.002042 ″	63.62 ″	63.81 ″ + .04357 ″	−.04361 ″ ″	63.81 ″ ″
65	104.6	1−.002113 ″	.002108 ″	64.59 ″	64.79 ″ + .04563 ″	−.04568 ″ ″	64.79 ″ ″
66	106.2	1−.002178 ″	.002171 ″	65.59 ″	65.79 ″ + .04778 ″	−.04783 ″ ″	65.79 ″ ″
68	109.4	1−.002312 ″	.002304 ″	67.55 ″	67.78 ″ + .05225 ″	−.05230 ″ ″	67.78 ″ ″
70	112.7	1−.002450 ″	.002441 ″	69.53 ″	69.76 ″ + .05699 ″	−.05705 ″ ″	69.76 ″ ″
72	115.9	1−.002592 ″	.002582 ″	71.47 ″	71.73 ″ + .06200 ″	−.06207 ″ ″	71.73 ″ ″
74	119.1	1−.002738 ″	.002727 ″	73.42 ″	73.71 ″ + .06730 ″	−.06738 ″ ″	73.71 ″ ″
75	120.7	1−.002813 ″	.002801 ″	74.39 ″	74.68 ″ + .07005 ″	−.07015 ″ ″	74.68 ″ ″
76	122.3	1−.002888 ″	.002876 ″	75.37 ″	75.69 ″ + .07289 ″	−.07298 ″ ″	75.69 ″ ″
78	125.5	1−.003042 ″	.003029 ″	77.33 ″	77.66 ″ + .07878 ″	−.07889 ″ ″	77.66 ″ ″
80	128.8	1−.003200 ″	.003186 ″	79.27 ″	79.63 ″ + .08497 ″	−.08510 ″ ″	79.63 ″ ″
82	132.0	1−.003362 ″	.003346 ″	81.21 ″	81.61 ″ + .09150 ″	−.09163 ″ ″	81.61 ″ ″
84	135.2	1−.003528 ″	.003510 ″	83.16 ″	83.58 ″ + .09834 ″	−.09849 ″ ″	83.58 ″ ″
85	136.8	1−.003613 ″	.003594 ″	84.13 ″	84.57 ″ + .1019 ″	−.1021 ″ ″	84.57 ″ ″
86	138.4	1−.003698 ″	.003679 ″	85.09 ″	85.55 ″ + .1055 ″	−.1057 ″ ″	85.55 ″ ″
88	141.6	1−.003872 ″	.003851 ″	87.03 ″	87.51 ″ + .1130 ″	−.1132 ″ ″	87.51 ″ ″
90	144.8	1−.004050 ″	.004026 ″	88.93 ″	89.46 ″ + .1209 ″	−.1211 ″ ″	89.46 ″ ″
92	148.1	1−.004232 ″	.004207 ″	90.89 ″	91.45 ″ + .1291 ″	−.1293 ″ ″	91.45 ″ ″
94	151.3	1−.004418 xb − 3.253 $r^2b^2 \times 10^{-6}$	.004390 ″	92.82 ″	93.40 ″ + .1376 ″	−.1379 ″ ″	93.40 ″ ″
95	152.9	1−.004513 ″ − 3.394 ″ ″	.004484 ″	93.78 ″	94.40 ″ + .1421 ″	−.1424 ″ ″	94.40 ″ ″
96	154.5	1−.004608 ″ − 3.539 ″ ″	.004578 ″	94.74 ″	95.37 ″ + .1466 ″	−.1469 ″ ″	95.37 ″ ″
98	157.7	1−.004802 ″ − 3.843 ″ ″	.004769 ″	96.66 ″	97.33 ″ + .1559 ″	−.1562 ″ ″	97.33 ″ ″
100	160.9	1−.005000 ″ − 4.167 ″ ″	.004964 ″	98.57 ″	99.29 ″ + .1656 ″	−.1660 ″ ″	99.29 ″ ″
105	169.0	1−.005512 ″ − 5.065 ″ ″	.005469 ″	103.4 ″	104.2 ″ + .1916 ″	−.1920 ″ ″	104.2 ″ ″
110	177.0	1−.006050 ″ − 6.101 ″ ″	.006000 ″	108.1 ″	109.1 ″ + .2201 ″	−.2207 ″ ″	109.1 ″ ″
115	185.1	1−.006612 ″ − 7.288 ″ ″	.006550 ″	112.8 ″	113.9 ″ + .2513 ″	−.2521 ″ ″	113.9 ″ ″
120	193.1	1−.007200 ″ − 8.640 ″ ″	.007125 ″	117.5 ″	118.8 ″ + .2851 ″	−.2861 ″ ″	118.8 ″ ″
125	201.2	1−.007812 ″ −10.17 ″ ″	.007726 ″	122.2 ″	123.6 ″ + .3223 ″	−.3234 ″ ″	123.6 ″ ″

TABLE CII—WILKINSON'S SIMPLIFIED FORMULAE FOR LONG 60 CYCLE LINES

DISTANCE MILES	DISTANCE KM.	a_1	ja_2	b_1	jb_2	c_1	jc_2
130	209.2	$1-.008450xb-11.90r^2b^2\times10^{-6}$	$.008353rb$	$126.9r$	$128.4x+.3622r^2b$	$-.3635rb^2\times10^{-6}$	$128.4b\times10^{-6}$
135	217.3	1−.009112 " − 13.84 "	.008994 "	131.5 "	133.3 " + .4053 "	−.4069 " "	133.3 " "
140	225.3	1−.009800 " − 16.01 "	.009664 "	136.1 "	138.1 " + .4516 "	−.4535 " "	138.1 " "
145	233.4	1−.01051 " − 18.42 " "	.01036 "	140.7 "	142.8 " + .5012 "	−.5035 " "	142.8 " "
150	241.4	1−.01125 " − 21.09 " "	.01107 "	145.2 "	147.6 " + .5544 "	−.5571 " "	147.6 " "
155	249.4	1−.01201 " − 24.05 " "	.01181 "	149.7 "	152.4 " + .6111 "	−.6143 " "	152.4 " "
160	257.5	$1-.01280xb+27.31(x^2b^2-r^2b^2)\times10^{-6}$	.01257 "	154.2 "	157.1 " + .6718 "	−.6756 " "	157.1 " "
165	265.5	1−.01361 " + 30.88 " "	.01335 "	158.7 "	161.8 " + .7356 "	−.7400 " "	161.8 " "
170	273.6	1−.01445 " + 34.80 " "	.01415 "	163.0 "	166.4 " + .8037 "	−.8088 " "	166.4 " "
175	281.6	1−.01531 " + 39.08 " "	.01498 "	167.4 "	171.2 " + .8757 "	−.8815 " "	171.2 " "
180	289.7	1−.01620 " + 43.74 " "	.01583 "	171.8 "	175.9 " + .9520 "	−.9588 " "	175.9 " "
185	297.7	1−.01711 " + 48.81 " "	.01670 "	176.1 "	180.5 " + 1.032 "	−1.040 " "	180.5 " "
190	305.8	1−.01805 " + 54.30 " "	.01759 "	180.3 "	185.1 " + 1.117 "	−1.126 " "	185.1 " "
195	313.8	1−.01901 " + 60.25 " "	.01850 "	184.6 "	189.7 " + 1.206 "	−1.216 " "	189.7 " "
200	321.9	1−.02000 " + 66.67 " "	.01943 "	188.7 "	194.4 " + 1.299 "	−1.311 " "	194.4 " "
205	329.9	1−.02101 " + 73.59 " "	.02038 "	192.9 "	198.9 " + 1.397 "	−1.410 " "	198.9 " "
210	338.0	1−.02205 " + 81.03 " "	.02135 "	197.0 "	203.5 " + 1.500 "	−1.514 " "	203.5 " "
215	346.0	1−.02311 " + 89.03 " "	.02235 "	201.0 "	208.0 " + 1.607 "	−1.624 " "	208.0 " "
220	354.1	1−.02420 " + 97.61 " "	.02336 "	205.1 "	212.6 " + 1.720 "	−1.738 " "	212.6 " "
225	362.1	1−.02531 " + 106.8 " "	.02440 "	209.0 "	217.0 " + 1.837 "	−1.857 " "	217.0 " "
230	370.1	1−.02645 " + 116.6 " "	.02545 "	212.9 "	221.4 " + 1.959 "	−1.982 " "	221.4 " "
235	378.2	1−.02761 " + 127.1 " "	.02652 "	216.8 "	225.9 " + 2.086 "	−2.112 " "	225.9 " "
240	386.2	$1-.02880xb+[138.2(x^2b^2-r^2b^2)+.7963r^2xb^3]\times10^{-6}$	.02760 "	220.7 "	230.3 " + 2.219 "	−2.248 " "	230.3 " "
245	394.3	1−.03001 " +[150.1 " + .9011 "] "	.02873 "	224.4 "	234.7 " + 2.357 "	−2.388 " "	234.7 " "
250	402.3	1−.03125 " +[162.8 " + 1.017 "] "	.02986 "	228.2 "	239.1 " + 2.500 "	−2.535 " "	239.1 " "
255	410.4	1−.03251 " +[176.2 " + 1.146 "] "	.03100 "	231.8 "	243.3 " + 2.648 "	−2.687 " "	243.3 " "
260	418.4	1−.03380 " +[190.4 " + 1.287 "] "	.03217 "	235.5 "	247.6 " + 2.802 "	−2.845 " "	247.6 " "
265	426.5	1−.03511 " +[205.5 " + 1.443 "] "	.03335 "	239.1 "	251.9 " + 2.962 "	−3.009 " "	251.9 " "
270	434.5	1−.03645 " +[221.4 " + 1.614 "] "	.03456 "	242.7 "	256.3 " + 3.127 "	−3.179 " "	256.3 " "
275	442.6	1−.03781 " +[238.3 " + 1.802 "] "	.03577 "	246.1 "	260.4 " + 3.298 "	−3.354 " "	260.4 " "
280	450.6	1−.03920 " +[256.1 " + 2.008 "] "	.03701 "	249.5 "	264.3 " + 3.475 "	−3.537 " "	264.3 " "
285	458.7	1−.04061 " +[274.9 " + 2.233 "] "	.03826 "	252.8 "	268.8 " + 3.657 "	−3.724 " "	268.8 " "
290	466.7	1−.04205 " +[294.7 " + 2.478 "] "	.03953 "	256.2 "	273.0 " + 3.846 "	−3.919 " "	273.0 " "
295	474.8	1−.04351 " +[315.6 " + 2.746 "] "	.04081 "	259.4 "	277.0 " + 4.040 "	−4.119 " "	277.0 " "
300	482.8	1−.04500 " +[337.5 " + 3.038 "] "	.04213 "	262.7 "	281.4 " + 4.240 "	−4.328 " "	281.4 " "

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